OPTIMIZATION METHOD APPLIED TO THE PRELIMINARY DESIGN OF A NAVAL SALVAGE TUG

by

GEORGE F.A. WAGNER

THESIS SUPERVISOR: P. MANDEL

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ABSTRACT

A non-economic optimization criterion is developed for a multi-mission naval salvage tug in this report. The optimization is carried out on a digital computer by the use of the exponential random search procedure in a multi-dimensional design space. The algorithm minimizes the quotient formed by dividing the life cycle cost of each design by the sum of a number of non-economic effectiveness measures of the design. The effectiveness measures chosen reflect the ability of the tug to meet its required towing mission and salvage mission. Sample results of the program are contained in section III of the paper.

The optimization criterion proved satisfactory, but, the method of computing individual requirement effectivenesses was not satisfactory in all cases. An improved method for computing the effectiveness of a design is recommended in Section V.

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I. INTRODUCTION

The exponential random search optimization technique, first applied to the design of ships in reference (13), has been applied to the optimization of an oil tankship in reference (22), and to the container ship problem in reference (9). All of these applications have been for commercial ships where clearly defined ship missions exist and "owner requirements" are available which specify items such as the trade route which the ship will travel, the required cargo deadweight, and a desired optimization criteria. Since these ships were designed for commercial ventures, a purely economic optimization criterion was appropriate. Suitable criteria were: maximize the capital recovery factor (CRF) of the operation, minimize the required freight rate(RFR), or minimize the sum of the acquisition and operating costs of the ship.

In this thesis the exponential random search optimization technique has been applied to a naval vessel. This poses a number of difficulties not encountered in the previous applications of the optimization scheme.

Naval ships have, in general, a multi-mission capability, and none of the missions are of an economic nature. Consequently, economic optimization criteria such as the capital recovery factor and the required freight rate are not suitable unless pseudo-monetary value can be attached to the various capabilities inherent in the ship and its mission.

The "least cost" ship optimization criterion can be readily used, but only if each of the ship's missions are completely specified. Furthermore, with the multiplicity of the ship missions, the least cost ship may not be as cost-effective as some other design which costs, perhaps, only slightly more.

In an attempt to investigate these problems, a dual mission salvage tug was chosen. This ship type has a required towing mission similar to that of an ocean going tug, and also a salvage mission which must be taken into consideration during the design phase. The optimization criterion selected was based on cost-effectiveness, where the costs are those of the twenty-five year life cycle of the ship. It was hoped that this optimization scheme would consider the disparity in costs in relation to the effectiveness of each design and select the one which was the most economical for the greatest effectiveness.

II. PROCEDURE

1. Ship Design Variables

For preliminary design purposes, a ship is completely defined when the following eight parameters are uniquely specified:

1) Full load displacement, Δ
2) Prismatic coefficient, Cp
3) Midship section coefficient, Cm
4) Length, L
5) Draft, T
6) Beam, B
7) Depth, D
8) Required installed shaft horsepower, SHP

By adopting the independent design variables listed in Table I, the above eight parameters can be expressed in terms of those variables and a specified ship velocity V as follows:

1) $\Delta = XV(1)$
2) $Cp = XV(5)$
3) The midship section coefficient can be related to the speed-length ratio (XV(2)) by*:

$$Cm = 0.977 + 0.018\,XV(2) + 0.076\,(XV(2))^2 - 0.115\,(XV(2))^3$$

4) $L = (V/XV(2))^2$
5) $T^2 = \dfrac{35\Delta}{L(B/T)CpCm}$

*Reference (1), Appendix 1, section 7.

$$T^2 = \frac{35 \cdot XV(1)}{(v/xv(2)) \cdot XV(3) \cdot XV(5) \cdot f(XV(2))}$$

$$T = \frac{XV(2)}{V} \sqrt{\frac{35 \cdot XV(1)}{XV(3) \cdot XV(5) \cdot f(XV(2))}}$$

6) $$B = \frac{B}{T} T = \frac{XV(3) \cdot XV(2)}{V} \sqrt{\frac{35 \cdot XV(1)}{XV(3) \cdot XV(5) \cdot f(XV(2))}}$$

7) $$D = \frac{L}{L/D} = \frac{V^2}{(XV(2))^2 \cdot XV(4)}$$

8) SHP = f(XV(1,2,3,4,5)) where a standard series is used to evaluate the powering requirements.

The variables as listed in Table I are the independent design variables which were used as the randomly generated variables in the exponential random search.

2. Mission Requirements

Table II lists those mission requirements which are an input to the computer program. In accordance with the ATS requirements as listed in reference (24), the maximum speed, endurance speed, and towing speed selected for use in this investigation were seventeen, thirteen, and seven knots respectively. Associated with those speeds were propulsive coefficients of 0.68, 0.75, and 0.65. The basic endurance range required was ten thousand miles at the endurance speed. The tow pull required was arbitrarily selected as one hundred and fifty-three thousand pounds, which is somewhat higher than that used for the ATS-1 design. The limiting draft was specified as fifteen feet in agreement with the

Table I

List of Independent Ship Design Variables

	Item	Symbol	Units	Variable
1)	Full Load Displacement	$\triangle$	long tons	XV(1)
2)	Speed-Length Ratio	$V/\sqrt{L}$	knots/(feet)$^{\frac{1}{2}}$	XV(2)
3)	Beam-to-Draft Ratio	B/T	feet/foot	XV(3)
4)	Length-to-Depth Ratio	L/D	feet/foot	XV(4)
5)	Prismatic Coefficient	C_p	non-dimen	XV(5)

Table II

List of Mission Requirements

1) The maximum speed of the ship
2) The endurance speed
3) The towing speed
4) The endurance range
5) The resistance of the towed vessel which the tug must be capable of towing
6) The maximum draft allowable for salvage and/or navigational reasons

salvage tug draft limitation.

3. Restrictions on Variables

The curves of reference (12) formed the basis of the data of the powering subroutine used in the design process. The ranges of applicability of that data introduce the relations:

$$0.001 \leq C_V \leq 0.006 \tag{1}$$

$$0.50 \leq \frac{V}{\sqrt{L}} \leq 1.20 \tag{2}$$

$$2.25 \leq \frac{B}{T} \leq 3.75 \tag{3}$$

$$0.48 \leq C_p \leq 0.70 \tag{4}$$

Equation (1) results in the following two relationships:

$$\frac{35\ XV(1)_{min} \left[XV(2)_{min}\right]^6}{(V_{max})^6} \geq 0.001 \tag{5}$$

$$\frac{35\ XV(1)_{max} \left[XV(2)_{max}\right]^6}{(V_{max})^6} \leq 0.006 \tag{6}$$

Equation (2) produces:

$$XV(2)_{max} \leq 1.20 \tag{7}$$

$$\frac{V_{min}}{V_{max}}\ XV(2)_{min} \geq 0.5 \tag{8}$$

Equation (3) requires that the variable XV(3) be bounded by:

$$XV(3)_{min} \geq 2.25 \tag{9}$$

$$XV(3)_{max} \leq 3.75 \tag{10}$$

Equation (4) limits the prismatic coefficient:

$$XV(5)_{min} \geq 0.48 \tag{11}$$

$$XV(5)_{max} \leq 0.70 \qquad (12)$$

An examination of reference (12) shows that the residual resistance coefficients do not change markedly in the neighborhood of a speed-length ratio of one-half for a wide range of prismatic coefficients. Since the speed-length ratio of the ATS type tug in the towing condition is below one-half, it was decided to use the resistance coefficient for a speed-length ratio of 0.5. This saved considerable computer time and did not result in the loss of accuracy.

4. The Convergent Exponential Random Search

What follows is a brief explanation of the search technique used in the exponential random search. For further details on the updating mechanism, see reference (13).

a. The exponential random search seeks to optimize an objective function, C, within an n-dimensional vector space. The n vectors (independent variables), XV, assume randomly generated values which lie within the specified upper and lower bounds of the variable in accordance with the updating mechanism. For each feasible solution arrived at in conjunction with previously calculated values of n-1 vectors and one randomly generated vector, the objective function C is calculated. The value of C is compared with the best previous approximation to the optimum, C^*, to determine if the latest result is an improvement. If it is an improvement, C^* is updated to the new value, and the randomly generated

vector associated with the C^* is then used in the updating mechanism. Upon termination of the search, C^* is assumed to be the true value of $\underline{C}$.

b. In this study there are five independent variables. An initial set of the variables is input to the computer program, as are the upper and lower bounds for each of the variables. The initial set of variable values are used at the outset as the best solution thus far obtained in the search. With this arrangement, the program enters the "zeroth" loop (loop is defined below) to attempt to obtain a feasible solution. If a valid solution is obtained, the search continues for the desired number of loops. If no feasible solution is obtained by the end of the zeroth loop, the search is terminated.

A sampling cycle consists of updating one of the variables to arrive at a new feasible solution. During the updating process, randomly generated values of the variable are calculated until a value which lies within the upper and lower bounds of the variable is found. With the new value, a new design is computed. If the design is acceptable, the sampling cycle is completed and the new objective function is compared with the previous best to see if it is an improvement. If the design is not acceptable, a new value of the variable is generated and the steps above repeated. For each variable, a maximum of five attempts is made to find an acceptable solution with the updated

value. If a new feasible solution with the variable is not formed after five attempts, the value of the variable is returned to the value that it held in the previous sampling cycle (i.e. the value that it had for the update of the previous variable). As a result, the values of the four variables which are not being updated during a sampling cycle, are the values of those variables which last resulted in a successful design.

A sampling loop, or "loop", consists of five sampling cycles, one for each of the independent variables, as defined in the previous paragraph. The zeroth loop therefore, evaluates twenty-five combinations of the independent variables in the case where no initial, feasible design is found before the search is terminated.

5. Program Heirarchy

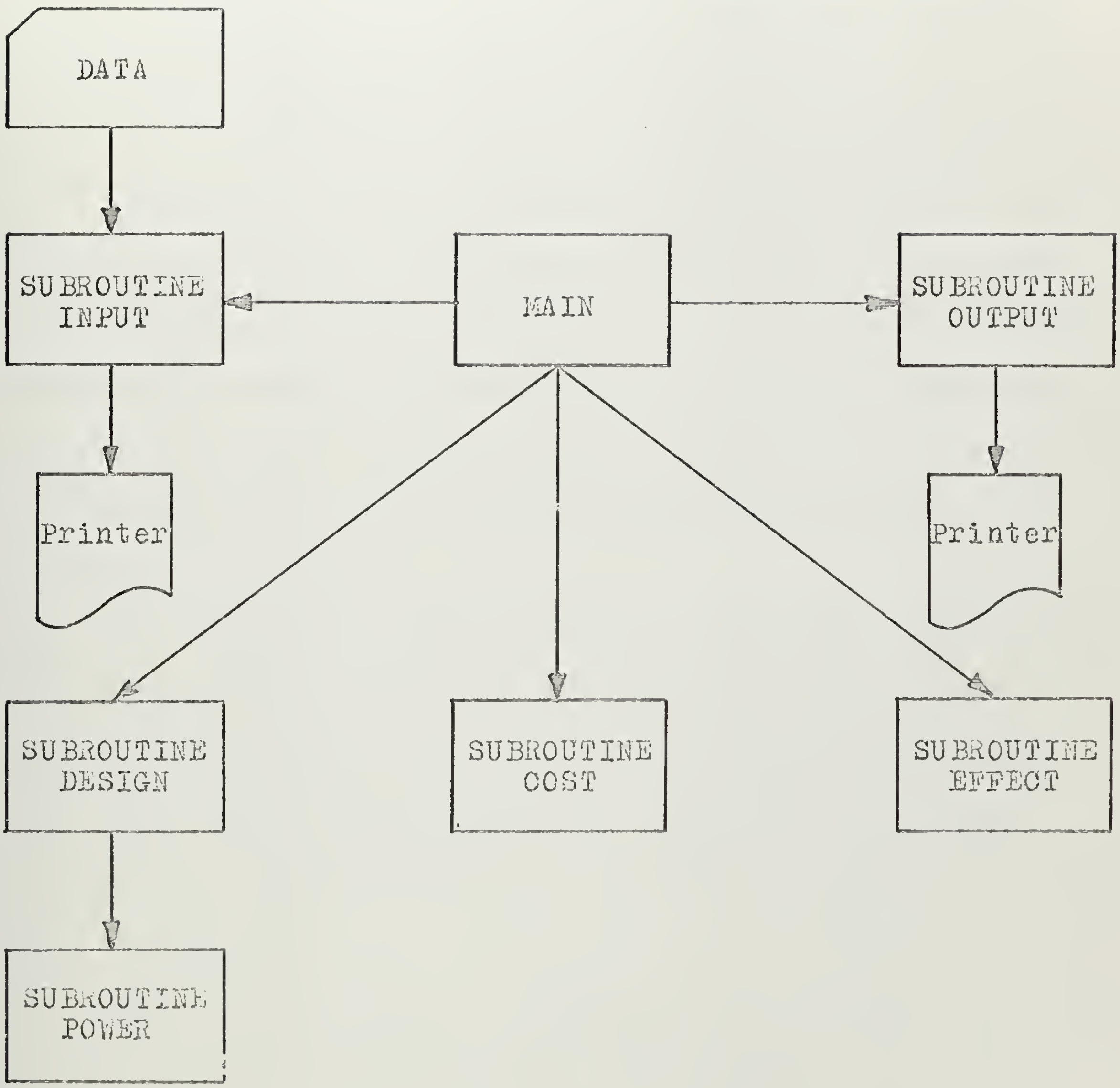
Figure I shows the logical heirarchy of the computer programs used in the tug optimization investigation.

The input subroutine is called at the beginning of the main program for the reading of the data cards. Once the data has been read, the input subroutine prints one page of output which lists the design and program requirements as specified in the data.

The design subroutine is called for every set of independent variables generated which lie within the variable ranges and for which the draft and freeboard are

Figure I

Logical Heirarchy of Programs



acceptable. The design subroutine in turn calls the powering subroutine three times, once for each of the three tug speeds under consideration. An error return is made from the design subroutine if any of the following conditions occur: endurance power exceeds the specified installed power, insufficient displacement for the weight sum, insufficient internal volume, or, inadequate stability.

If an error return is made from the design sub-program, a new set of random variables is generated. If the design is adequate, the cost subroutine is called to calculate the acquisition cost, the annual costs, the annual maintenance and repair costs, and the twenty-five year life cycle cost. The effectiveness value, and the cost-effectiveness quotient is computed.

For designs of equal or better merit than the previous best, the output subroutine is called to print a page of intermediate output concerning the last evaluated design. The loop number is listed on this page to aid in identification of the portion of the search in which the design was found.

At the completion of the search, the design, cost, and output subroutines are called to re-evaluate the design which was found to be the best. A two page output is printed for the optimum design (see appendix F).

6. The Cost-Effect Analysis

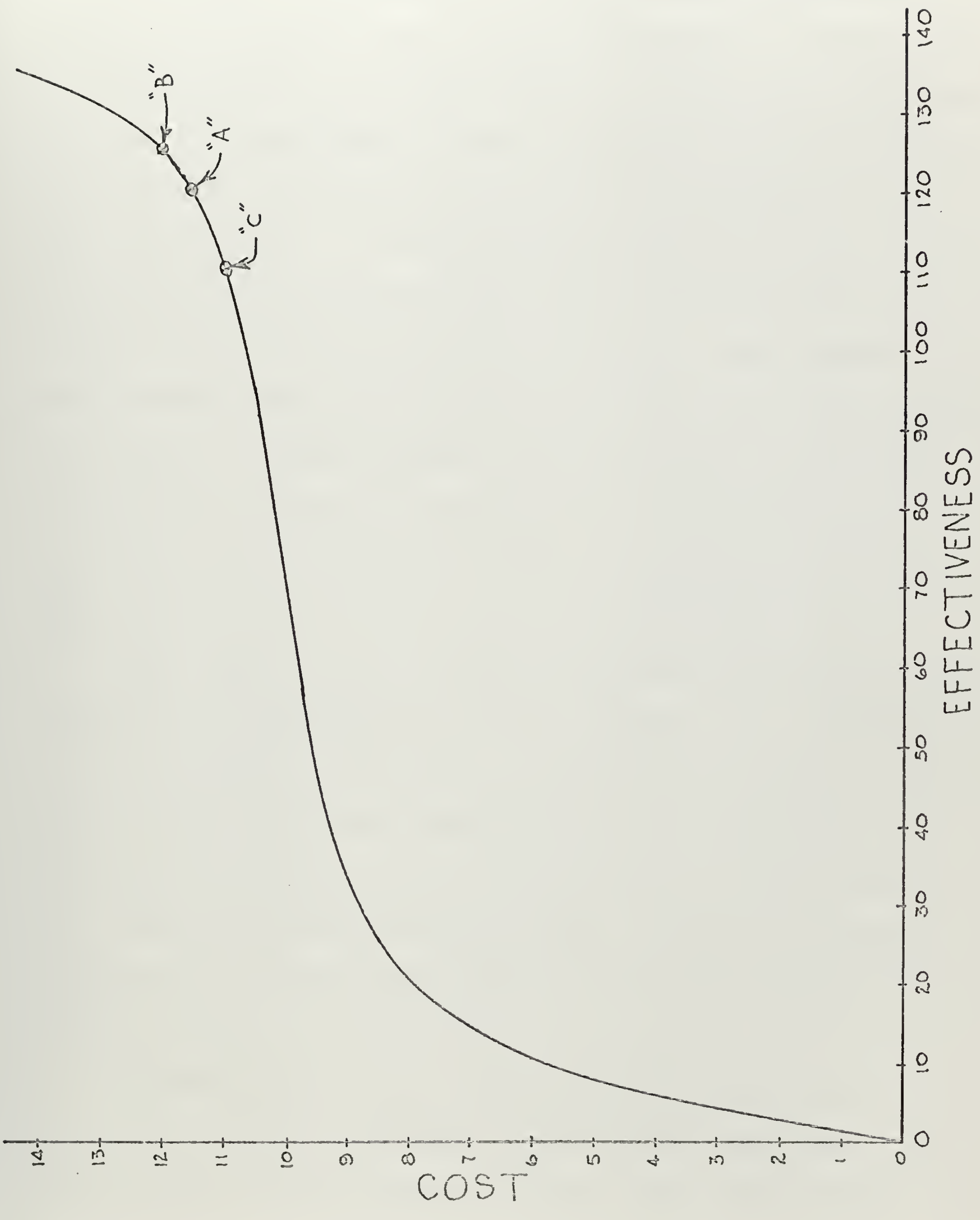
In a cost-effectiveness analysis, costs are typically plotted as the ordinate of a graph whose abscissa is measured in units of effectiveness. A possible graph of this type to represent the cost to effectiveness relationship for a ship concept is shown in Figure II.

At low effectivenesses, the cost increases rapidly for increased effectiveness. At intermediate effectivenesses, the slope of the cost-effectiveness curve decreases from what it was at the lower effectiveness and the cost does not increase so rapidly with increased effectiveness. At higher effectivenesses, the slope of the curve increases again and the cost, once again, begins to increase rapidly for added effectiveness. In selecting the optimum design in such a case, the practice is to select the point on the curve in the intermediate effectiveness region just short of the point where the costs begin to increase rapidly with effectiveness. An example of such a selection is point "A" in Figure II. However, equally likely points of selection could very well have been points "B" or "C" in Figure II. The selection of such an optimum point is, therefore, very subjective and unsuitable for computer use.

The above technique could be adapted to computer use if a desired slope of the cost-effectiveness curve could be specified. The selection of such a slope might be difficult in the case where the effectiveness is measured in terms of

Figure II

Sample Cost versus Effectiveness Curve



pure numbers. The difficulty would arise in assessing the merit of spending so many additional dollars for a unit of effectiveness. This approach could, however, be readily applied in the case where the effectiveness is measured in economic terms. A possible example of this type of application is cost measured in annual investment in an enterprise and effectiveness measured in terms of anticipated annual after-tax profit. A slope of unity would be an upper limit because at that point an additional dollar invested would result in an additional dollar of profit. Any greater slope would result in a loss on the additional investment. If, instead, surplus capital could be invested elsewhere at an after tac rate of return R, the desired slope of the cost-effectiveness curve would be reduced to the quotient $\frac{1}{1+R}$.

This type of approach would have been difficult for the salvage tug investigation for two reasons. The effectiveness is not an economic quantity, so attempting to select a proper slope on the cost-effectiveness curve would have been difficult. Secondly, since the costs were to be computed for randomly generated ship designs, a smooth cost-effectiveness curve would not be produced by the plotting of all of the points.

Consequently, a new optimization criterion had to be devised which would not suffer from these weaknesses. It was desired that the criterion should pick the cheapest

ship from among ships of equal effectiveness and select the ship with the greatest effectiveness from a group of ships of equal cost. The method which these requirements suggested, and the one which was adopted for use, was the minimization of the quotient formed by dividing the cost by the ship effectiveness. Figure III shows graphically the results of applying this optimization method to the cost-effectiveness curve of Figure II. This amounts to finding the effectiveness for which the cost per unit of effectiveness is the cheapest.

The minimum point of a curve occurs at the point where the slope of the curve is zero. Applying this to the criterion selected above,

$$\frac{d}{dE}\left(\frac{C}{E}\right) = 0$$

at the optimum solution. If this is expanded,

$$\frac{1}{E^2}\left(E\frac{dC}{dE} - C\frac{dE}{dE}\right) = 0$$

and, after rearranging terms,

$$\frac{dC}{dE} = \frac{C}{E}$$

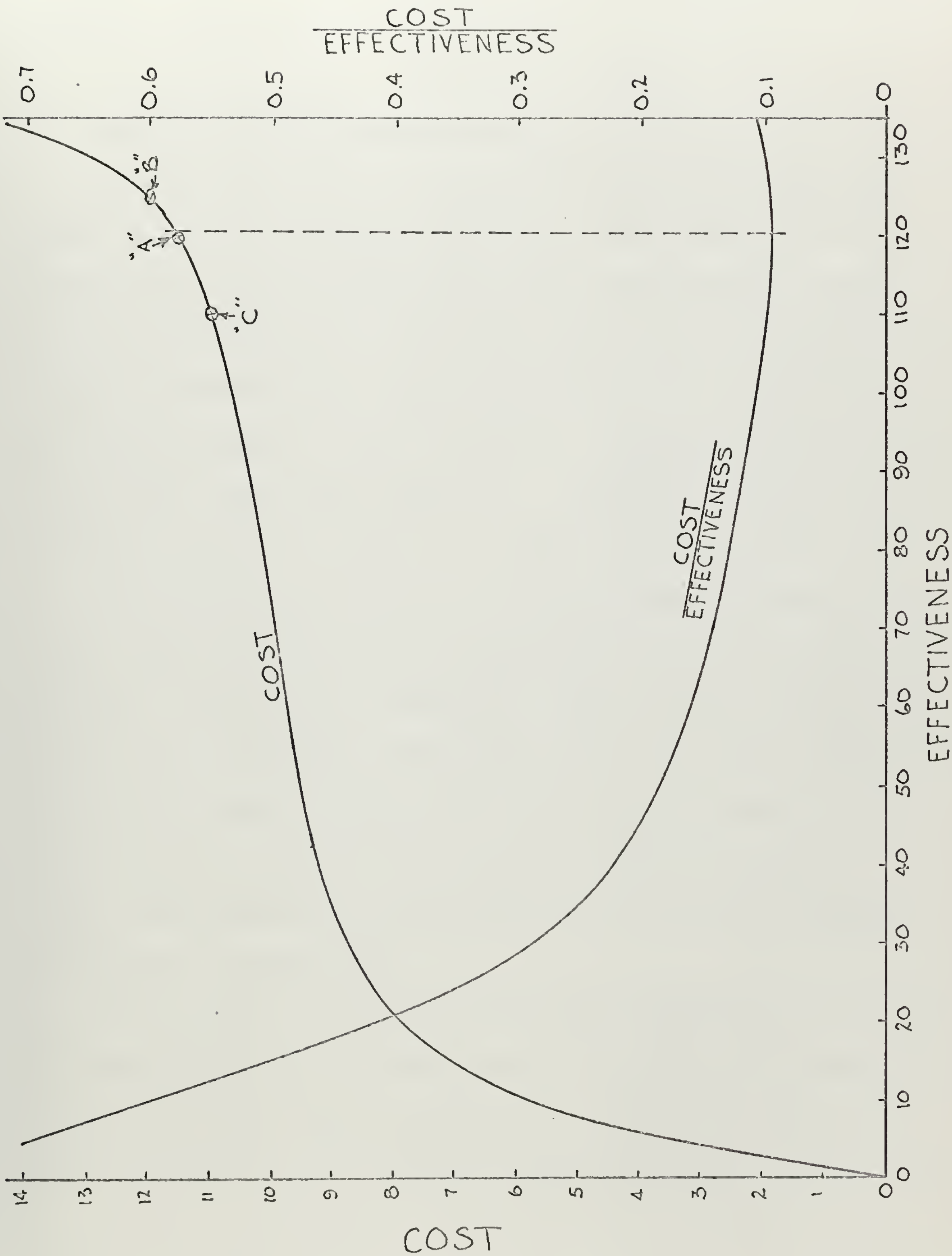
at the minimum point of the cost divided by the effectiveness curve.

Essentially, this criterion solves the cost-effectiveness problem by finding the point on the cost versus effectiveness curve at which the slope of the curve is equal to the cost divided by the effectiveness.

This provides, in part, an answer to the problem previously mentioned concerning selection of a suitable slope

Figure III

Optimization Criterion Applied to Cost-Effectiveness Curve



to use in determining the optimum point on a cost-effectiveness curve. This method has the merit of assuring the greatest effectiveness per dollar.

7. Cost and Effectiveness Measures

The two missions of a salvage tug, ship salvage and ocean towing of disabled ships, are both responses to unpredictable emergencies which makes anticipating annual operations difficult. The ships may also be used for routine service towing (e.g. target sleds), but this is a secondary purpose. As a result, no attempt was made to compute annual operating expenses. Instead, a "cost of availability" was used, based on a twenty-five year life cycle.

The cost of availability is the present value of the costs which will be incurred over the life of the ship to maintain the ship in readiness. This includes the acquisition cost, the annual crew costs, and the annual maintenance and repair costs. The present value of the annual costs were computed using a four percent rate of interest. The cost estimating relationships used for the cost analysis are shown in Table III.

The annual maintenance and repair costs were estimated by using Figure 30 of reference (3). The costs predicted from that figure were increased by twenty-five percent to make allowances for a diesel engine propulsion system*, and

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* Reference (3), page 29.

Table III

Cost Estimating Relations

weight group 1	hull structure	$2000 /ton
weight group 2	propulsion	$6000 /ton
weight group 3	electric plant	$8000 /ton
weight group 4	communication and control	$10000/ton
weight group 5	auxiliary systems	$4000 /ton
weight group 6	outfit and furnishings	$5000 /ton
weight group 7	armament	$10000/ton
crew	officers	$15000/year
	chief petty officers	$10000/year
	other enlisted men	$ 6000/year

also upgraded at four percent interest to make allowances for cost increases since the paper was published.

Eight measures of effectiveness were postulated with which to measure the ability of the tug to fulfill the towing and salvage missions. They were: endurance range, towing pull power, deck area available aft of the towing winch, the bollard pull provided, the draft of the ship, the availability of volume for ballast, the excess volume available internally, and the amount of metacentric height provided beyond that required.

The endurance range was used because the design program computes the weight available for fuel from the slack between the weight sum and the full load displacement. As a result, the range of a design may vary significantly from the required input range. The effectiveness number is computed by dividing the range provided by the range required and then deducting one, or,

$$E_{endur} = \left(\frac{\text{actual endurance}}{\text{required endurance}} - 1 \right) \tag{13}$$

Hence, if the design provides exactly the required range, the effectiveness number is zero.

There are two methods of employing the effectiveness of the endurance. In one, there is no penalty assigned if the endurance range exceeds that required, nor is additional credit given for the added range. In the second, excess endurance is considered to be unwarranted; consequently, the effectiveness is deductive. In both cases insufficient endurance decreases the effectiveness.

The towing pull effectiveness was incorporated in the same manner as was the endurance range and can be written as:

$$E_{tow} = \left(\frac{\text{actual towline pull}}{\text{required towline pull}} - 1 \right) \qquad (14)$$

In this case, the actual towing pull power developed is determined by the powering requirements. The power available for the towing pull is the difference between the power required for the tug in the towing condition and the maximum installed power.

The deck area available aft was included since added deck area provides increased work area, which is desirable, and also additional temporary stowage area. In this case, the actual deck area provided was normalized by the amount of deck area available on the ATS-1, approximately four thousand square feet. It can be written as:

$$E_{deck\ area} = \left(\frac{\text{deck area aft}}{4000} - 1 \right) \qquad (15)$$

Bollard pull was considered desirable for salvage work primarily. As a consequence, the effectiveness number for the bollard pull was determined by a comparison of the bollard pull developed in relation to the pull developed by the beach gear carried aboard since both are used to develop static pull.

$$E_{bollard\ pull} = \left(\frac{\text{bollard pull}}{896{,}000} + 1 \right) \qquad (16)$$

While the maximum allowable draft of the ship is a program input, a reduction in draft would be desirable from the salvage viewpoint since a shallower draft ship can work

in closer than one with a deeper draft. The effectiveness number was computed by deducting from one the ratio of actual draft to limiting draft:

$$E_{draft} = \left(1 - \frac{\text{actual draft}}{\text{maximum draft}} \right) \tag{17}$$

Ballast was included primarily for stability reasons in the less than full load condition. The program evaluates the initial stability in the full load condition. There was no way to estimate stability in lighter conditions without makine the programs much more complex. As a result, ballast was considered necessary for stability purposes in lighter than the full load condition. The amount of ballast which can be carried is determined by the amount of excess volume available after all other volume requirements have been satisfied. Ballast does not enter the weight equations since it is carried only in light conditions. If sufficient volume is available for ballast of ten percent of the full load displacement, no more ballast is added and the remainder of the volume goes to excess volume. If sufficient ballast can be carried, the effectiveness number is zero, and decreases uniformly to minus one at the point where no space is available for ballast. The effectiveness number for ballast is:

$$E_{ballast} = \left(\frac{\text{volume available for ballast}}{\text{volume required for ballast}} - 1 \right) \tag{18}$$

$$0 \leq E_{ballast} \leq 1$$

The excess volume is included as a measure of the salvage mission effectiveness. For some salvage assignments

it is necessary to carry additional salvage equipment beyond the normal allowance of the ship. For such occurances, the extra internal volume would be required for protective stowage of the equipment. The effectiveness number for the excess volume is computed by dividing the excess volume by the volume assigned for salvage equipment stowage, or:

$$E_{volume} = \left(\frac{\text{excess volume}}{34430} \right) \qquad (19)$$

Additional stability beyond that required, as measured by the GM, is also beneficial for the salvage mission, in that it increases the over-the-side heavy lift capability of the tug. The effectiveness number is obtained by dividing the excess GM by the required GM.

$$E_{stability} = \left(\frac{\text{excess GM}}{\text{required GM}} \right) \qquad (20)$$

The effectiveness numbers were each multiplied by a normalizing factor in an attempt to equalize their weight in the effectiveness calculation. The normalizing factors were found by generating two hundred random designs within the variable ranges and printing the resultant effectiveness numbers. For each measure of effectiveness, the arithmetic mean of the numbers was computed and considered to be the expected value of that effectiveness measure. The normalizing factors were then computed by scaling the mean values obtained to the desired level.

The endurance and towing pull were considered to be primarily measures of the towing effectiveness. The deck area aft is necessary for both the towing and salvage missions

and, therefore, was considered mutually desirable for both missions. The remainder of the effectiveness measures were assumed to be desirable for the salvage capability.

In order to give equal weight to the towing and salvage missions, the two towing effectivenesses were normalized to a value of two and one-half. The five salvage effectivenesses were normalized to unity, and the after deck area effectiveness to one and three-quarters. In this manner, the towing and salvage mission effectivenesses sum to the same number. In addition, weighting factors can be applied to the effectiveness measures to put emphasis on specific requirements. These weighting factors are an input to the program.

The total effectiveness of a design is computed by adding to one hundred the sum of the eight individual effectivenesses. The basic one hundred was arbitrarily selected for addition to the effectiveness so that large weighting factors could be used without the effectiveness dominating the cost in the calculation of the cost-effectiveness quotient.

III. RESULTS

Results obtained from a number of trials are contained in this section. The runs were made using a combination of two required endurance ranges and two required towing pulls. The weighting factors were also varied to compare the effects that the weighting factors have on the search.

For all of the runs the maximum shaft horsepower required was computed by the program. The towing pulls were selected so that in one case the required pull would be large enough so that the maximum power would be dictated by the towing requirement and in the other case low enough so that the maximum speed of 17.2 knots would determine the power requirement.

All runs were made using five hundred search loops. This means that there was a maximum of twenty-five hundred valid designs which could have been generated. Other design requirements common to all of the runs are listed in Table IV.

The remark "sufficient" for the amount of ballast provided, indicates that adequate volume was available for ballast tanks. The ballast tankage should have capacity for ballast water weighing one-tenth of the ship's full load displacement. Excess stability is computed by deducting one-tenth of the ship's beam from the metacentric height.

A plot of the cost-effectiveness curve of run number 1 is included after the tabulation to show the general shape of the curves obtained.

Table IV

Design Requirements

Operating Characteristics:

Maximum Allowable Draft = 15.0 feet

Speed Requirements:

Maximum speed = 17.2 knots,
propulsive coefficient = 0.680
Endurance speed = 13.0 knots,
propulsive coefficient = 0.750
Towing speed = 7.0 knots,
propulsive coefficient = 0.650

Armament Requirements:

Armament weight = 2.34 tons
Ammunition weight = 11.20 tons
Ammunition volume = 500 cubic feet

No restriction was placed on maximum installed horsepower.

A penalty was assigned for excess endurance and excess towing pull in the effectiveness calculation.

Search Requirements:

First 350	loops	updating exponent = 1
next 100	loops	updating exponent = 3
next 25	loops	updating exponent = 5
next 25	loops	updating exponent = 7

Parameters Controlling Search:

	Minimum	Maximum	Initial
Displacement	2000.000	2600.000	2277.300
Speed-Length Ratio	0.850	1.090	1.053
Beam-to-Draft Ratio	2.250	3.750	3.542
Length-to-Depth Ratio	9.000	14.000	12.500
Prismatic Coefficient	0.480	0.650	0.542

Table V

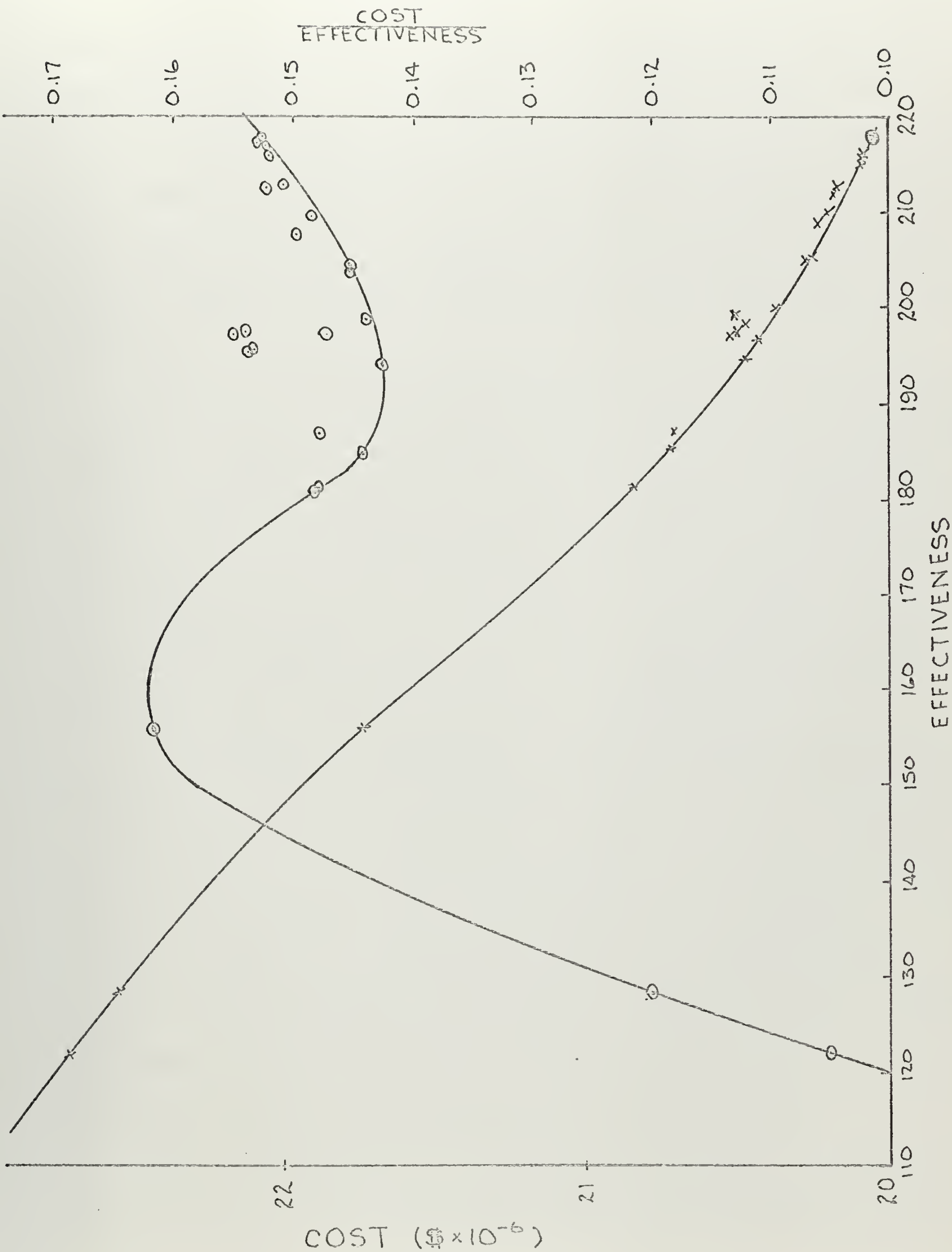
	1		2		3	
Input:	1		2		3	
(1) Range, nautical miles	10000		10000		10000	
(2) Towing Pull, pounds	153000		153000		153000	
Design Variables:						
(3) Displacement	2559.7		2355.4		2263.2	
(4) $V/\sqrt{L}$	0.994		1.026		1.025	
(5) B/T	3.695		3.698		3.448	
(6) L/D	13.85		13.73		13.65	
(7) C_p	0.480		0.499		0.523	
Effectivenesses:	wt	eff	wt	eff	wt	eff
(8) Endurance, eq.(13)	5	-.774	1	-.228	5	-.263
(9) Tow Pull, eq. (14)	5	0.0	1	0.0	1	0.0
(10) Deck Area, eq.(15)	5	88.67	1	9.497	1	2.830
(11) Bollard Pull, eq.(16)	5	4.914	1	0.983	1	0.982
(12) Ballast, eq.(18)	5	0.0	1	0.0	1	0.0
(13) Draft, eq.(17)	5	4.915	1	1.189	1	1.255
(14) Excess Volume, eq.(19)	5	5.451	1	0.462	1	0.460
(15) Excess Stability, eq.(20)	5	14.35	1	2.719	1	0.748
(16) Total Effectiveness	217.524		114.562		106.012	
Costs in Millions of Dollars:						
(17) Acquisition Cost	9.580582		8.851829		8.528556	
(18) Life Cycle Cost	22.034561		20.655350		20.132278	
(19) Cost/Effectiveness	C.1013		0.1803		0.1899	
Results:						
(20) Endurance, naut. miles	9897.9		9810.2		10034.7	
(21) Tow Pull, pounds	153000.		153000.		153000.	
(22) Deck Area Aft, sq. ft.	4895.		4479.		4143.	
(23) Bollard Pull, pounds	87456.		87211.		87053.	
(24) Ballast	sufficient		sufficient		sufficient	
(25) Draft, feet	13.28		12.92		12.81	
(26) Excess volume, cu. ft.	20434.		8652.		8619.	
(27) Excess Stability, feet	4.22		3.89		0.99	
Ship Particulars:						
(28) L.B.P., feet	299.20		281.23		281.53	
(29) Beam, feet	49.08		47.78		44.15	
(30) Draft, feet	13.28		12.92		12.81	
(31) Depth, feet	21.60		20.49		20.63	
(32) C_p	0.480		0.499		0.523	
(33) C_m	0.957		0.951		0.951	
(34) C_b	0.459		0.475		0.498	
(35) C_v	0.00334		0.00371		0.00355	
(36) C_{wp}	0.723		0.723		0.726	
(37) Maximum SHP	3498.3		3488.5		3482.1	
(38) Towing EHP	683.9		664.2		631.3	
(39) Wetted Surface, sq. ft.	13366.4		12431.7		12121.2	
(40) Total Volume, cubic feet	213285.		191412.		186604.	
Crew:						
(41) Off., CPO, E.M.	6+5+64=75		6+4+59=69		6+4+57=67	
Program Information:						
(42) Designs Evaluated	1492		1475		1497	
(43) Number of Improvements	27		23		4	

Input:	4		5		6		7	
(1)	10000		10000		8000		8000	
(2)	153000		153000		153000		153000	
Design Variables:								
(3)	2355.4		2353.8		2231.1		2465.4	
(4)	1.026		1.024		1.035		1.013	
(5)	3.698		3.731		3.740		3.464	
(6)	13.73		13.83		13.91		12.92	
(7)	0.499		0.502		0.517		0.488	
Effectivenesses:	wt	eff	wt	eff	wt	eff	wt	eff
(8)	1	-.288	1	-.158	1	-.042	5	-.125
(9)	1	0.0	1	0.0	1	0.0	1	0.0
(10)	1	9.497	1	9.679	1	5.409	1	10.59
(11)	5	4.913	1	0.983	1	0.982	1	0.983
(12)	1	0.0	1	0.0	1	0.0	1	0.0
(13)	1	1.189	5	6.294	1	1.482	1	0.792
(14)	1	0.462	1	0.529	1	0.405	1	1.012
(15)	1	2.719	1	2.731	1	2.330	1	1.336
(16)	114.562		120.058		110.566		114.393	
Costs:								
(17)	8.851829		8.840995		8.500536		9.343431	
(18)	20.655350		20.644333		20.100179		21.598160	
(19)	0.1803		0.1720		0.1818		0.1888	
Results:								
(20)	9810.2		9895.8		7589.0		8013.2	
(21)	153000.		153000.		153000.		153000.	
(22)	4479.		4488.		4273.		4535.	
(23)	87211.		87222.		87105.		87263.	
(24)	sufficient		sufficient		sufficient		sufficient	
(25)	12.92		12.80		12.41		13.62	
(26)	8652.		9924.		7589.		18976.	
(27)	3.89		3.90		3.24		1.89	
Ship Particulars:								
(28)	281.23		282.00		276.22		288.48	
(29)	47.78		47.75		46.41		47.16	
(30)	12.92		12.80		12.41		13.62	
(31)	20.49		20.40		19.86		22.33	
(32)	0.499		0.502		0.517		0.488	
(33)	0.951		0.952		0.950		0.954	
(34)	0.475		0.478		0.491		0.466	
(35)	0.00371		0.00367		0.00371		0.00359	
(36)	0.723		0.724		0.725		0.723	
(37)	3488.5		3488.9		3484.2		3490.5	
(38)	664.2		664.7		642.1		663.3	
(39)	12431.7		12454.0		12002.7		12811.2	
(40)	191412.		192548.		184244.		207790.	
Crew:								
(41)	6+4+59=69		6+4+59=69		6+4+57=67		6+5+62=73	
Program Information:								
(42)	1475		1479		1413		1623	
(43)	23		32		26		9	

Input:	8		9		10		11	
(1)	8000		8000		10000		10000	
(2)	123000		123000		123000		123000	
Design Variables:								
(3)	2260.7		2171.3		2206.2		2310.9	
(4)	1.038		1.035		1.024		1.023	
(5)	3.590		3.239		3.606		3.582	
(6)	13.40		13.14		13.84		13.45	
(7)	0.497		0.506		0.555		0.518	
Effectivenesses:	wt	eff	wt	eff	wt	eff	wt	eff
(8)	1	-.096	1	-.003	5	-.285	5	-.300
(9)	1	-1.898	5	-4.448	1	-1.440	5	-6.933
(10)	1	5.666	1	-.689	1	1.358	1	5.853
(11)	1	0.978	1	0.971	1	0.975	1	0.975
(12)	1	0.0	1	0.0	1	0.0	1	0.0
(13)	1	1.122	1	0.967	1	1.724	1	1.296
(14)	1	0.235	1	0.156	1	1.198	1	0.953
(15)	1	2.295	1	0.231	1	0.231	1	1.203
(16)	108.302		97.185		103.761		103.047	
Costs:								
(17)	8.575994		8.238901		8.286319		8.647259	
(18)	20.166489		19.189117		19.346024		20.141754	
(19)	0.1862		0.1974		0.1864		0.1955	
Results:								
(20)	7949.1		7998.3		9962.4		9960.4	
(21)	144479.		133066.		139297.		138692.	
(22)	4286.		3965.		4069.		4295.	
(23)	82463.		76134.		79737.		79473.	
(24)	sufficient		sufficient		sufficient		sufficient	
(25)	13.04		13.31		11.99		12.73	
(26)	4404.		2921.		22462.		17861.	
(27)	3.22		0.30		0.30		1.64	
Ship Particulars:								
(28)	274.68		275.98		282.36		282.50	
(29)	46.81		43.10		43.23		45.62	
(30)	13.04		13.31		11.99		12.73	
(31)	20.50		21.00		20.41		21.01	
(32)	0.497		0.506		0.555		0.518	
(33)	0.949		0.949		0.952		0.952	
(34)	0.472		0.480		0.528		0.493	
(35)	0.00382		0.00362		0.00343		0.00359	
(36)	0.723		0.724		0.731		0.725	
(37)	3298.5		3045.4		3189.5		3178.9	
(38)	647.7		609.3		627.0		645.4	
(39)	12006.3		11699.5		12029.9		12308.3	
(40)	182319.		174600.		195861.		197093.	
Crew:								
(41)	6+4+57=67		5+4+53=62		5+4+54=63		6+4+56=66	
Program Information:								
(42)	1546		1383		1514		1388	
(43)	30		14		8		14	

Figure IV

Example Program Cost-Effectiveness Curve



IV. DISCUSSION OF RESULTS

The use of high weighting factors in the effectiveness calculation, as in design number one, makes the choice of the optimum design more sensitive to the effectiveness than to the cost. This is exhibited in designs number one and two where the relative weights of the effectivenesses to each other are the same. The higher weights cause the range of the effectiveness sums to increase while the range of the costs do not change.

Putting a larger weighting factor on one of the effectivenesses than on the others did cause the design selected as the optimum to improve in the more heavily weighted effectiveness when compared with a run where it was not emphasized. An example of this is design number three in which the endurance more closely approached the required ten thousand mile endurance than it did in run number two.

An examination of designs numbered ten and eleven indicates that penalizing the effectiveness for exceeding the requirements is not justified. In these designs a penalty was assigned for exceeding their required towing pull of 123,000 pounds. Both designs exceeded this amount; and, design ten slightly more than design eleven. However, design ten appears more attractive in terms of what it provides than does design eleven, and at a cheaper price.

From an examination of the eleven designs, it appears that the normalizing factor for the effectiveness provided

by deck area aft was too large. As a result, when attempting to drive some of the effectivenesses to zero, the deck area effectiveness overpowered the total effectiveness calculation and the desired result was not achieved as well. The program found it easy to increase the effectiveness more readily by increasing the length and beam of the ship, which increases the deck area, than by forcing, for example, the endurance effectiveness from a negative fraction to zero. Since the ship dimensions increased then, so did the cost. Design number seven is a good example of this occurrance. While the endurance did approach the required eight thousand miles, the ship increased in size and cost over design number six.

Designs six and seven point out another fact. If the weighting factors used in design seven are applied to the effectivenesses of design six and the cost-effectiveness quotient computed, design six is superior to design seven. This means that had the combination of variables of design six been found during the search in design seven, an improved ship would have resulted.

Bollard pull effectiveness remained approximately constant for all eleven designs and, therefore, effectively did not enter into the computations. This seems to indicate that the effectiveness parameter associated with bollard pull need not have been considered.

The ability to determine the sensitivity of the cost to changes in the effectiveness requirements is hampered

in this method since all of the effectiveness measures collectively change from one design to another. It would be desirable to be able to determine the cost sensitivity to one parameter while holding all others constant.

Figure IV is a plot of the cost versus effectiveness curve and of the cost effectiveness quotient versus effectiveness for design number one. It does not exhibit the properties of Figure III because of the randomness of the designs generated. It is also limited because only designs which had lower cost-effect quotients than the previous best were printed out and hence available for plotting. It appears in this case that the true minimum was not reached in the cost effectiveness quotient since the quotient plot does not have a zero slope at the final design. Also, the slope of the cost versus effectiveness curve does not equal the value of the cost-effectiveness quotient.

V. CONCLUSIONS AND RECOMMENDATIONS

The optimization criterion selected, minimizing the cost-effectiveness quotient, was valid. The results displayed the trade-off in cost for effectiveness and effectiveness for cost throughout the design evaluations, in attempting to get the greatest effectiveness per dollar.

Five hundred search loops for the random search was inadequate as shown by designs six and seven. The search of design seven was not intensive enough to find the number six design variables which would have resulted in an improved ship. An increased number of loops would allow a more thorough search of the design space.

A systematic (parametric) search of the space would probably be more exhaustive. The problem here, however, is that the number of trials would have to be very high in order to provide a fine enough grid of the space. Since the total number of combinations for this type of search is the product of the number of increments of each of the parameters, the total number of trials grows rapidly. For the ranges of Table IV, incrementing the displacement by twenty tons, the speed-length ratio by two one-hundredths, the beam-to-draft ratio by one-tenth, the length- to-depth ratio by one-half, and the prismatic coefficient by one-tenth for a systematic search results in almost one and one-half million combinations. This corresponds to approximately sixty thousand random search loops if five attempts are required

for each sampling cycle. Search time equivalence would probably allow in excess of one hundred thousand loops in the ransom search. Five thousand random search loops would probably provide an adequate search of the space.

The method of measuring the individual effectivenesses were not, in all cases, adequate. Penalizing or giving credit to an effectiveness measure for exceeding the requirements tends to distort the results. This was displayed when attempting to provide 123,000 pounds of towing pull when excess towing pull was provided due to the powering requirement.

An improved method would be to be able to specify requirements for the effectiveness measures, penalize for failing to reet the requirements, but giving no credit, either positive or negative, for exceeding the requirement. For measures which it would be desirable to maximize or minimize (e.g. ship draft, internal volume, etc.), measures of effectiveness of the form of equation 17 would be necessary. Decreasing the ship drafts for example, in the salvage tug, allows the tug to operate in more restricted waters. Giving additional credit for a shallower draft would be justified, and the design search would attempt to minimize the draft without sacrificing too much cost. The amount of cost which the user was willing to sacrifice would be determined by the weighting factor; the higher the weighting factor, the more cost would be sacrificed.

An alternative approach, and one which would aid in the determination of the cost sensitivity to mission requirements, is to conduct a systematic (parametric) search by varying the mission and effectiveness requirements independently while using the exponential random search for the design variables to find the optimum design for each condition. In this approach, the effectiveness factors would have to be calculated in such a manner that the effectiveness would be maximized by all requirements being exactly met.

This approach does have its shortcomings, however. First, it suffers from the rapid growth of the number of combinations in a parametric search. As an example, if the ballast effectiveness measure were removed by not accepting ships with insufficient volume for ballast, and neglecting the bollard pull effectiveness, leaving six measures for which three values of each requirement were to be tried, there would be 3^6 combinations. This would result in 729 random searches to find the optimum ship for each requirments combinations. Secondly, actually determining the cost sensitivity to changes in the requirements would be difficult. If just one requirement were altered over a range while all of the other requirements remained fixed, it would be a simple matter. If sensitivity of several of the requirements are desired, however, the inter-relationships become more complex. Consequently, deciding exactly which measures the

costs are sensitive to becomes more difficult.

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VI. APPENDIX

APPENDIX A

Details of Programs

This appendix describes the programs by briefly describing the operations being carried out within the "boxes" inserted in the program listings contained in Appendix E. Each box contains a set of calculations or manipulations which would appear in a flow chart.

I. Main Routine

Box 1	The input subroutine is called which reads the input data and prints the first page of the program output.
Box 2	Variables are initialized in this box, as is the random number generator.
Box 3	The random search loop counter is established in this box.
Box 4&5	A check is made in this box to see what value the random search updating exponent is to take on.
Box 6	The index of the random variable to be updated is controlled by this box. The value of the variable being updated which yielded the last satisfactory design is stored as XSAVE in this box.
Box 7	This box contains the counter of the number of attempts made in order to get a complete sampling cycle by a random variable.
Box 8	The random variable is updated in this box. A check is made to see if the newly selected value of the variable lies within the specified minimum and maximum values of the variable also. If it does not, a new value is selected. If it does, control passes to box 9.
Box 9	The ship dimensions and coefficients are computed in this box. Depending upon the variable being updated, only certain of the dimensions need be recomputed. The design subroutine is then called, and upon return a check is made to determine if the design was satisfactory.

Box 10 The cost and effectiveness subroutines are called in this box. The counter for successful designs is incremented if no error resulted in the effectiveness subroutine, and the new cost-effectiveness quotient compared with the previous best to determine if the new is equal to a better than the old.

Box 11 For each cost-effectiveness quotient which is equal to or better than the previous best, the value of CSTAR is changed to the quotient just found. The output subroutine is then called to print the intermediate output for the new design, after which the values of the random variables are saved in the array XB.

Box 12 If an unsuccessful attempt was made to update a random variable five times, the value of that variable which last resulted in a successful design is returned to the variable. The ship dimensions and coefficients are then recomputed since they will have been changed during the attempt to update the variable.

Box 13 Not used.

Box 14 This box is used in determining if a successful design was reached in the initial loop.

Box 15 This box is the location of the completion of the random search.

Box 16 The design which yielded the best solution is recomputed in this box so that additional information about it can be output.

Box 17 The output information of the optimum design is printed when the output subroutine is called.

2. Input Subroutine

The input subroutine reads in the Taylor residual resistance coefficients for the powering subroutine and the program input data. The subroutine then prints a page of output which lists the input design requirements.

3. Random Number Generator

The random number generator generates a series of

numbers which lie between the limits of zero and one for use in the search updating mechanism.

4. Design Subroutine

Box 1 The error code is initialized.

Box 2 The cubic number of the design is computed.

Box 3&4 Not used.

Box 5 The type of powering calculation is determined.

Box 6 When an input power is not specified, control passes to this box. The shaft horsepower required for the towing condition and for maximum speed is calculated.

Box 7 The program chooses the maximum of the powers calculated in Box 6 as the required installed power.

Box 8 The shaft horsepower needed for the endurance speed is calculated and then the towing pull power available is calculated.

Box 9 If the installed power is specified, control passes to this box. Here the power required for the endurance speed is calculated, and a check made to determine if this power exceeds the installed power. If it does, an error is detected and control passed to Box 22.

Box 10 The actual towline pull available is calculated after the towing power is determined.

Box 11 The light ship weights are calculated for each weight group and the light ship displacement determined.

Box 12 The full load displacement is computed here after the weight of crew, provisions and stores are computed.

Box 13 The margins are computed and the full load displacement with margins computed.

Box 14 The fuel weight is computed by deducting the sum of the weights computed to this box from the full load displacement specified by variable XV(1). If the available fuel weight is zero or less, the

error indicator is set.

Box 15 Not used.

Box 16 The total internal volume is estimated by scaling up the gross bale cubic by the square root of the total midship section area divided by the waterline section area. The superstructure volume is then added to the hull volume.

Box 17 The volume requirements are determined in this box, volume allotted for ballast and the external volume computed.

Box 18 The stability is computed here and the excess GM determined.

Box 19 The actual endurance which results from the amount of fuel carried and the power requirements is computed.

Box 20 The bollard pull in pounds is figured out.

Box 21 The square footage of clear deck area aft is determined.

5. Cost Subroutine

Box 1 The acquisition costs of the standard navy weight groups are computed using the cost estimating relations and the computed weight group weights.

Box 2 A percentage is added for the cost of the margin.

Box 3 A percentage is added for design and construction costs.

Box 4 An allowance is made for price escalation.

Box 5 Profit is assumed to be seven percent of the preceeding cost.

Box 6 An allowance is added for changes which may occur.

Box 7 A post-delivery allowance is added to the cost.

Box 8 A percentage is added for quality assurance.

Box 9 The cost of shock requirements is added.

Box 10 The annual crew wages are computed in this box.

Box 11 Maintenance and repair costs are computed.

Box 12 The present value of twenty-five years of maintenance and repair costs is computed in this box.

Box 13 The present value of the life cycle cost is computed.

6. Effectiveness Subroutine

Box 1 Initializes the error return code.

Box 2 Calculates the values of the eight measures of effectiveness.

Box 3 Determines if penalties are to be assigned for endurance or towing pull depending upon the input value of the effectiveness mode indicator.

Box 4 The effectiveness is calculated.

Box 5 The cost-effectiveness quotient is computed in this box.

7. Powering Subroutine

The powering subroutine is the same as that used in reference (9) and is based on Taylor's Standard Series, reference (11).

8. Output Subroutine

The output subroutine prints the output of the program. If no initial, feasible solution is found it prints non-zero values of the variables which were calculated so that the user can determine the proper course of action to take to obtain a feasible solution. For a complete run, the output subroutine prints a page of output for each improved or equally cost-effective design which occurs. Upon completion of the program it prints a two page output listing which provides additional data on the optimum design.

APPENDIX B

Details of Calculations

1. Main Routine

The details of the main routine were given in the preceeding appendix. The dimensions and coefficients are computed in box sixteen of the main routine. The midship coefficient is computed using a formula presented in reference (13). The minimum allowable freeboard is based on a curve presented in reference (18). The remaining dimensions and coefficients are computed using standard naval architecture relationships and equations.

2. Design Subroutine

The design algorithm contains the mathematical model of the salvage tug. It first computes the weights of the seven standard weight groups, the weights of the provisions and stores, the margin weights, and the fuel weight. The internal volume available is then approximated and the volume requirements computed. The stability, endurance range, bollard pull, and deck area aft are then computed.

The seven standard weight groups are estimated by using curves fitted through data points provided by references (4), (5), and (17), and reference (21) in the case of weight group one. The sum of these weight groups is the light ship displacement.

The crew size is roughly approximated by assuming a certain portion of the crew to be fixed and the remainder to be a function of the ship size and power. The constants

in the equation were determined by using the data for the ATS and the FY67 ATF design. While not very refined, the equation proved adequate. Of the crew, 8.4 percent are assumed to be officers, 6.3 percent are assumed to be chief petty officers, and the remainder are assumed to be enlisted hands.

The weights required for crew, stores, and repair parts are based on data in the weight statements of references (5) and (17), and reference (2). The salvage weights were assumed to be the same as provided for the ATS design.

The margin weights are taken as a percentage of the light ship displacement in the same proportion as they were in the ATS design. The margin weight totals seven percent of the light ship displacement.

The weight available for fuel is computed by finding the excess weight between the weight sum, FLDIS(2), and the random variable ship displacement.

The internal volume of the hull is computed by scaling the gross bale cubic of the hull by the square root of the midship section area to the main deck divided by the midship section area to the waterline. This method was arrived at after several other methods were investigated to suitably approximate the volume of the ATS-1 hull. The ATS-1 volume was determined by integrating the body plan section areas. The ATS-1 has a raised deck for the forward half of the length of the ship which made approximating the

volume difficult. The superstructure is assumed to contain two deck, the upper one six feet less wide than the lower, and both one-quarter of the length of the ship long.

Engineering space length is computed by adding the end clearances allowed in the ATS design to the engine length. While diesel engines come in discrete lengths, an examination of reference (11) showed that due to the variety of engines available from the several manufactures, the length could be considered as a continuous function for purposes of approximation. Fairbanks Morse engines were used to construct the length equations.

The volume requirements for the provisions and stores are computed using stowage factors provided in reference (5). The volumes required for the crew's habitability spaces are computed using the guidance of reference (23). The remaining volumes are estimated by relations developed after conducting a volume analysis of the ATS-1 design.

3. Cost Subroutine

The basic ship cost is computed using the cost estimating relations listed in Table III. To the base price, the following cost percentages are added:

Margin	7%
Design and Construction	8%
Escalation	3%
Profit	7%
Change Orders	1%
Post Delivery Expenses	½%
Quality Assurance	1%
Shock Requirements	2%

The acquisition cost is the cost which results when the above cost percentages are applied to the basic cost as outlines in reference (1).

The annual crew wages are computed using the annual wage listed in Table III. These figures are merely approximations which are to include annual pay, subsistence, and the pro-rated cost of the supporting naval establishment.

The annual maintenance and repair costs are estimated by an equation derived from the curves of Figure 30 of reference (3). The costs predicted by that figure have been increased by twenty-five percent to make allowances for a diesel engine propulsion plant, and also upgraded at four percent interest to make allowance for cost increases since reference (3) was published.

APPENDIX C

Program Variables

The following is a list of the variables which appear in the programs. Numbers in parenthesis following the variable names indicate the dimension of the variables. Names listed under the heading "program" indicate that the variable is calculated in that sub-program.

VARIABLE	PROGRAM	REMARKS
AM	DESIGN	The area of the midships section of the underwater body at the full load displacement.
AMI	DESIGN	The area of the midships section to the main deck intersection at side.
AN	INPUT	The floating point representation of the specified number of loops which the search is to conduct.
ARMMNT		A program input which is the weight of the ship armament in tons.
B	MAIN	The ship beam in feet.
BM	DESIGN	Metacentric radius.
BMARG	DESIGN	The builder's margin which is taken as one percent of the light ship displacement.
BOLPUL	DESIGN	The bollard pull developed.
BREQ	DESIGN	The beam required in order to be able to fit four diesel engines abreast.
CANDE	DESIGN	The weight in tons of the ship officers, crew and effects.
CB	MAIN	The block coefficient.

VARIABLE	PROGRAM	REMARKS
CDT	DESIGN	A number used in calculating the provisions required for the crew for sixty days.
CHILL	DESIGN	The weight of chilled stores required for the crew.
CHGS	DESIGN	A weight allowance for change orders which is taken as 1.2% of the light ship displacement.
CM	MAIN	The midship section coefficient.
CPO	DESIGN	The number of chief petty officers which is computed as 6.3% of the crew size.
CR(6210)		An array containing Taylor's resistance data. The data is a program input.
CREW	DESIGN	The required number of personnel for the tug.
CS(3)	COST	(1) The acquisition cost. (2) The annual crew wages. (3) The annual maintenance and repair costs.
CST	COST	Interim value of the acquisition cost. Contains life cycle cost upon completion of the subroutine.
CSTAR	MAIN	The value of the minimum CSTEFF found in the search.
CSTEFF	EFFECT	The quotient formed by dividing the life cycle cost by the ship effectiveness.
CSTWG(7)	COST	The estimated construction costs for the seven navy weight groups.
CUBIC	DESIGN	The ship's cubic number.
CV	MAIN	The volumetric coefficient.
CWP	DESIGN	The waterplane coefficient.
D	MAIN	The depth of the hull at the midship section.

VARIABLE	PROGRAM	REMARKS
DIESEL	DESIGN	The required power output for each of four installed diesel engines.
DIST		An input specifying the required endurance range of the tug.
DKAFT	DESIGN	The deck area aft of the towing machine.
DMARG	DESIGN	The design margin which is assumed to be 4% of the light ship displacement.
DRY	DESIGN	The weight of dry provisions required for the crew.
E(8)	EFFECT	The measures of effectiveness: (1) Endurance (2) Pulling power (3) Deck area aft (4) Bollard pull (5) Ballast (6) Draft (7) Excess volume (8) Excess stability
EFF	EFFECT	The relative effectiveness of the design under consideration.
EHP	POWER	The effective horsepower of the tug at the towing speed.
ELNSTS	DESIGN	The weight of electronic stores carried.
EM	DESIGN	The number of enlisted men in the crew.
EMB	DESIGN	One hundres and five percent of EM in the crew.
ENDUR	DESIGN	The actual endurance range realized with the weight of fuel allowed by a design.
ENGL	DESIGN	The length of one of the four diesel engines in the propulsion plane.
ENGSPL	DESIGN	The required length of the engineering spaces.

VARIABLE	PROGRAM	REMARKS
FBDACT	MAIN	The actual freeboard resulting in the full load condition.
FBDMIN	MAIN	The minimum allowable freeboard.
FLDIS(2)	DESIGN	(1) Full load displacement without margins. (2) Full load displacement with margins.
FOAM	DESIGN	The weight of salvage foam carried.
FREEZE	DESIGN	The weight of frozen food required for the crew.
FUELWT	DESIGN	The weight of fuel carried.
GALLEY	DESIGN	The volume required for the galley.
GAS	DESIGN	The weight of the compressed gas carried.
GENSTS	DESIGN	The weight of the general stores required.
GFM	DESIGN	The weight of the government furnished material not included in the weight groups.
GMACT	DESIGN	The resulting metacentric height of a design.
HD	DESIGN	The required number of items for the crew's sanitary spaces.
I	MAIN	An index used in updating the values of the random variables.
I	INPUT, OUTPUT	An integer used in establishing arrays.
IJ	MAIN	An integer used in updating the value of the random variables which yielded an improved solution.
IM(4)	INPUT	The number of loops which will be searched at each of the four updating exponents.

VARIABLE	PROGRAM	REMARKS
I1	INPUT	An index used in reading input arrays.
I2	INPUT	An index used in computing the values of IM.
J	INPUT	An index used in establishing the array MEXP.
K	INPUT	An index used in establishing the array W.
K1	MAIN	The number of successful designs evaluated.
L	MAIN	The random search loop counter.
LOADS	DESIGN	The weight of the consumables plus the salvage equipment.
M	MAIN	The value of the exponent for the random search updating mechanism.
MEXP(4)		The input values of the desired updating exponents for the random search.
MODE		An input which effects the calculation of EFF. See User Instructions for use.
MODEP		An input which specifies the type of powering calculation desired. See User Instructions for use.
N		The required number of loops specified as an input.
NCPO	DESIGN	The integer number of chief petty officers in the crew.
NEM	DESIGN	The integer number of enlisted men in the crew.
NEMB	DESIGN	The integer number formed by increasing NEM by five percent.
NERR	DESIGN, EFFECT	An error flag used in the subroutines to indicate that the design does not meet the specified requirements.

VARIABLE	PROGRAM	REMARKS
NLAV	DESIGN	The number of lavatories required for the crew wash rooms.
NOFF	DESIGN	The integer number of officers in the crew.
NSH	DESIGN	The number of showers required for the crew.
NUR	DESIGN	The number of urinals required for the crew.
NWC	DESIGN	The number of water closets required for the crew.
N1	OUTPUT	The type of output data: 1 = output for no solution 2 = intermediate improvement output 3 = final output
OFF	DESIGN	The number of officers in the crew represented in floating point notation.
OILLUB	DESIGN	The required weight of lubricating oil for the engines.
PANTRY	DESIGN	The volume required for the wardroom pantry.
PC(3)		The specified values of the propulsive coefficients for the towing, endurance, and full speeds.
PROVS	DESIGN	The weight of the provisions required for the crew.
REPSTS	DESIGN	The weight of the repair stores.
RKB	DESIGN	The height of the vertical center of buoyancy above the base.
RKG	DESIGN	The height of the vertical center of gravity above the base.
SALVG	DESIGN	The weight of the salvage gear.
SG300	DESIGN	The weight of the electrical power generation equipment.

VARIABLE	PROGRAM	REMARKS
SG301	DESIGN	The weight of the power distribution switchboards.
SG3023	DESIGN	The weight of the lighting and power distribution system cable.
SG3501	DESIGN	The weight of the electric plant repair parts and the generator fluids.
SHIPST	DESIGN	The weight of the ship store stores.
SHP	POWER, DESIGN	The maximum installed horsepower for a design.
SHPEND	POWER, DESIGN	The shaft horsepower required at the endurance speed.
SHPINS		The value of the maximum shaft horsepower if the power is an input.
SHP1	POWER, DESIGN	The shaft horsepower required at the maximum speed.
SHP2	POWER, DESIGN	The shaft horsepower required for the towing condition.
SL	MAIN	The ship length between perpendiculars.
SMLSTS	DESIGN	The weight of the small stores carried.
SSB1	DESIGN	The breadth of the lower superstructure deck.
SSB2	DESIGN	The breadth of the upper superstructure deck.
STORES	DESIGN	The sum of the general stores, electronic stores, and the repair stores.
STSMED	DESIGN	The weight of the medical stores.
ST3	DESIGN	The sum of SG300, SG301, and SG3023.

VARIABLE	PROGRAM	REMARKS
T	MAIN	The draft of the tug in feet.
TEMP	DESIGN, COST	Used to store an intermediate arithmetic result.
TIME(4)		The fraction of the total number of search loops to be spent at each of the four updating exponents.
TMAX		An input which limits the maximum value of the ship's draft.
TOWPOW	DESIGN	The equivalent horsepower of the input value of the tow resistance.
TOWPUL	DESIGN	The actual amount of towing pull power available from the power plant selected.
TOWRES		The required towing pull of the tug in pounds.
VAMMO		An input which specifies the amount of internal volume required for the ship's ammunition.
VBAGS	DESIGN	The volume required for the crew's baggage stowage.
VBAL(2)	DESIGN	(1) The required volume for the ballast tankage. (2) The excess volume beyond that which is required.
VBERTH	DESIGN	The internal volume required for crew berthing spaces.
VCHILL	DESIGN	The volume required for CHILL.
VCOS	DESIGN	The volume reserved for the Commanding Officer's storeroom.
VCPOBK	DESIGN	The volume required for the chief petty officer bunkroom.
VCPOHD	DESIGN	The volume needed for the chief petty officer's sanitary space.
VCPOM	DESIGN	The volume required for the chief petty officer messroom.

VARIABLE	PROGRAM	REMARKS
VDIVSH	DESIGN	The volume of the diving shop.
VDRY	DESIGN	The volume required for dry provisions.
VELNST	DESIGN	The volume required by the electronic stores.
VEMBR	DESIGN	The volume of the enlisted men's berthing spaces.
VEMHD	DESIGN	The volume of the enlisted men's sanitary facilities.
VEMM	DESIGN	The volume required for the enlisted men's mess.
VFAN	DESIGN	The volume needed for fan rooms and uptake spaces.
VFRZ	DESIGN	The volume required by the frozen foods.
VFUEL	DESIGN	The volume needed for the stowage of fuel.
VGENST	DESIGN	The volume required for the general stores stowage.
VGRDTK	DESIGN	The volume required for the chain locker and windlass room.
VHD	DESIGN	The volume required for the sanitary spaces on the ship.
VKTS		The input which specifies the required endurance speed.
VLIQ	DESIGN	The volume of the liquids which are carried by the ship.
VLKRS	DESIGN	The volume of the foul weather gear, deck gear, and cleaning gear lockers.
VLUBE	DESIGN	The volume required for stowage of the lube oil.
VMACH	DESIGN	The volume required for the main and auxiliary machinery spaces.

VARIABLE	PROGRAM	REMARKS
VMAX		The input value of the maximum ship speed.
VMED	DESIGN	The volume required for the stowage of the medical stores.
VMESS	DESIGN	The volume needed for the crew messing spaces.
VMISSH	DESIGN	The volume required for the repair lockers, I.C. and gyro room, the M/G room, machine shop, carpenter shop, and filter cleaning shop.
VOFFCS	DESIGN	The volume needed for departmental and executive office spaces.
VOFFHD	DESIGN	The volume for the officer's sanitary spaces.
VOFFSP	DESIGN	The total volume required for administrative and operational spaces.
VOFFSR	DESIGN	The volume required for the officer staterooms.
VOL	DESIGN	The total internal volume available on the ship.
VOLREQ	DESIGN	The total volume required for all purposes.
VOPSSP	DESIGN	The volume needed for the operation department spaces.
VPASSG	DESIGN	The volume reserved for passageways throughout the ship.
VREPST	DESIGN	The volume required for the repair stores.
VRTMOM	DESIGN	The vertical moment of all weights.
VSALSH	DESIGN	The volume of the salvage shop.
VSALVS	DESIGN	The volume required for the salvage stores.
VSERVS	DESIGN	The volume of the ship service spaces.

VARIABLE	PROGRAM	REMARKS
VSHOPS	DESIGN	The volume of all of the shops.
VSHST	DESIGN	The volume required for the ship stores.
VSKBAY	DESIGN	The volume required for the sick bay and sanitary space.
VSMLST	DESIGN	The volume required for the small stores stowage.
VSTRGR	DESIGN	The volume required for the steering gear room.
VSTRS	DESIGN	The internal volume required for all stores excluding the salvage stores.
VTOW		The input which specifies the desired towing speed. It is the speed for which TOWRES must be computed.
VWATER	DESIGN	The fresh water tankage volume required.
VWINDL	DESIGN	The volume required for the anchor windlass room.
W(8)		The weighting factors for the effectiveness calculation. These are input data.
WATER	DESIGN	The weight of fresh water required for the ship.
WETSUR	POWER, DESIGN	The wetted surface of the ship's hull.
WTAMMO		The weight of ammunition which the ship must carry. This is input data.
WTGPLS(7)	DESIGN	The weights of the seven standard navy weight groups.
WTLS	DESIGN	The light ship displacement without margins.
WTLSM	DESIGN	The light ship displacement with margin weights.

VARIABLE	PROGRAM	REMARKS
XB(5)	MAIN	The values of the five independent variables which has yielded the best design.
XMAX(5)		The maximum permissable values which the five random variables may assume.
XMIN(5)		The minimum values which the five random variables may assume.
XSAVE	MAIN	The value of the random variable being updated which resulted in the last valid design.
XSGM	DESIGN	The excess metacentric height beyond the required ten percent of the ship beam.
XSVOL	DESIGN	Any excess volume which results after the volume calculations have been completed.
XV(5)	MAIN	The value of the random variable being updated and the values of the four random variables not being updated which resulted in the last valid design.
ZZZ	MAIN	Variable used when initializing the random number generator.

APPENDIX D

User Instructions

When using the program, it is first necessary to establish upper and lower limits for the five design variables. The variable limits selected must satisfy the inequalities (5) through (12). Initial values for the random variables must also be selected by the user. Naturally, these values should lie within the variable limits. It is not necessary that the set of initial variable values result in a satisfactory design. If the initial values are not valid, the program attempts twenty-four randomly generated combinations in an attempt to find an initial, feasible solution. If it is successful, it continues for the specified number of loops. If it is not successful, it prints an output page which can help the user determine what changes are necessary to obtain a feasible design. An example of an unsuccessful design is included in appendix F.

The user has an option as to the type of powering calculation desired. The installed horsepower may be specified by the user or, the program can calculate the maximum required horsepower. The powering mode indicator is as follows:

0 Program calculates power required.

1 Installed horsepower is specified.

Another user option occurs in the choice of effectiveness

calculation. Here there are four mode indicators which have the following result:

Mode Indicator	Result
0	The endurance effectiveness is zero if the actual endurance exceeds the required.
1	Excess endurance causes a decrease in effectiveness.
2	Towing pull power greater than the specified required pull decreases the effectiveness.
3	Additional endurance and extra towing pull power are both considered unnecessary and degrade the effectiveness.

The following data cards must be provided:

Card	Columns	Format	Data
1-1035	22-63	6F7.3	Taylor Standard Series residual resistance coefficients
1036	1-4	I4	number of loops desired
	6-10	F5.3	percent of number of loops at first exponent
	16-20	F5.3	percent of number of loops at second exponent
	26-30	F5.3	percent of number of loops at third exponent
	36-40	F5.3	percent of number of loops at final exponent
	46-47	I2	first exponent for search
	51-52	I2	second exponent for search
	56-56	I2	third exponent for search
	61-62	I2	final exponent for search

Card	Columns	Format	Data
1037	16-25	F10.5	lower limit of displacement
	31-40	F10.5	upper limit of displacement
	46-55	F10.5	initial displacement
1038	16-25	F10.5	lower limit of speed-length ratio
	31-40	F10.5	upper limit of speed-length ratio
	46-55	F10.5	initial speed-length ratio
1039	16-25	F10.5	lower limit of beam-to-draft ratio
	31-40	F10.5	upper limit of beam-to-draft ratio
	46-55	F10.5	initial beam-to-draft ratio
1040	16-25	F10.5	lower limit of length-to-depth ratio
	31-40	F10.5	upper limit of length-to-depth ratio
	46-55	F10.5	initial length-to-depth ratio
1041	16-25	F10.5	lower limit of prismatic coefficient
	31-40	F10.5	upper limit of prismatic coefficient
	46-55	F10.5	initial prismatic coefficient
1042	6-10	F5.2	maximum allowable draft
	21-30	F10.2	desired endurance range
1043	6-10	F5.2	maximum speed
	16-20	F5.3	propulsive coefficient at maximum speed

Card	Columns	Format	Data
1044	6-10	F5.2	endurance speed
	16-20	F5.3	propulsive coefficient at endurance speed
1045	6-10	F5.2	towing speed
	16-20	F5.3	propulsive coefficient in towing condition
1046	5	I1	powering mode indicator
	11-20	F10.3	tow resistance
	26-35	F10.3	installed power if powering mode indicator is not zero
1047	11-20	F10.2	armament weight
	26-35	F10.2	ammunition weight
	41-50	F10.2	ammunition stowage space volume
1048	5	I1	effectiveness mode indicator
	6-10	F5.1	weighting factor for endurance
	11-15	F5.1	weighting factor for towing pull
	16-20	F5.1	weighting factor for deck area
	21-25	F5.1	weighting factor for bollard pull
	26-30	F5.1	weighting factor for ballast
	31-35	F5.1	weighting factor for ship draft
	36-40	F5.1	weighting factor for excess volume
	41-45	F5.1	weighting factor for excess stability

APPENDIX E

The Fortran IV listings of the main program, subroutines, and function used in this study are included in this appendix.

```
C         SALVAGE TUG OPTIMIZATION
      DIMENSION CR(6210), CS(3), CSTWG(7), E(8), FLDIS(2), IM(4),
     1MEXP(4), PC(3), TIME(4), VBAL(2), W(8), WTGPLS(7), XB(5),
     2XMAX(5), XMIN(5), XV(5)
      COMMON/I/ IM, K1, MEXP, MODE, MODEP, N, NCPO, NEM, NOFF
      COMMON/R/ AN, ARMMNT, B, BM, BMARG, BOLPUL, CANDE, CB, CHGS, CM,
     1CPO, CR, CS, CST, CSTEFF, CSTWG, CV, CWP, D, DIST, DKAFT, DMARG,
     2E, EHP, EM, ENDUR, ENGSPL, FBDACT, FLDIS, FCAP, FUELWT, GAS, GFM,
     3GMACT, OFF, OILLUB, PC, PROVS, RKB, RKG, SHP, SHPEND, SHPINS, SL,
     4SSB1, STORES, SALVG, T, TIME, TMAX, TOWPUL, TOWRES, VAMMO, VBAGS,
     5VBAL, VBERTH, VFAN, VFUEL, VGRDTK, VHD, VKTS, VLKRS, VLUBE, VMACH,
     6VMAX, VMESS, VOFFSP, VOL, VPASSG, VSALVS, VSHOPS, VSTRGR, VSTRS,
     7VTOW, VWATER, W, WATER, WETSUR, WTAMMO, WTGPLS, WTLS, WTLSM, XB,
     8XMAX, XMIN, XSGM, XSVOL, XV
C BOX 1
      CALL INPUT
C BOX 2
      SL = 0.0
      B = 0.0
      T = 0.0
      D = 0.0
      FBDACT = 0.0
      CM = 0.0
      CB = 0.0
      CV = 0.0
      EHP = 0.0
      WETSUR = 0.0
      SHP = 0.0
      SHPEND = 0.0
      DO 20 J = 1,5
      XV(J) = XB(J)
      WTGPLS(J) = 0.0
      E(J) = 0.0
   20 CONTINUE
      DO 21 J = 6,8
      WTGPLS(J-1) = 0.0
      E(J) = 0.0
   21 CONTINUE
      WTLS = 0.0
      FUELWT = 0.0
      ENDUR = 0.0
      VOL = 0.0
      XSVOL = 0.0
      RKG = 0.0
      RKB = 0.0
      BM = 0.0
      GMACT = 0.0
      CS(1) = 0.0
      CST = 0.0
      CSTAR = 10000.0
      NERR = 0
      IJ = 0
      K1 = 0
```

```
      ZZZ = RAND(-1.0)
      N = N + 1
C BOX 3
      DO 150 L = 1,N
C BOX 4 AND 5
      IF(L - IM(1))40,40,41
   40 M = MEXP(1)
      GO TO 60
   41 IF(L - IM(2))42,42,43
   42 M = MEXP(2)
      GO TO 60
   43 IF(L - IM(3))44,44,45
   44 M = MEXP(3)
      GO TO 60
   45 M = MEXP(4)
C BOX 6
   60 DO 150 I = 1,5
      XSAVE = XV(I)
C BOX 7
      DO 129 J = 1,5
C BOX 8
   80 XV(I) = XB(I) + (XMAX(I) - XMIN(I))*((2.0*RAND(0.0) - 1.0)**M)
      IF(XV(I) - XMIN(I))80,81,81
   81 IF(XMAX(I) - XV(I))80,82,82
   82 IF(L - 1)91,91,90
C BOX 9
   90 GO TO (93,91,95,98,94),I
   91 SL = (VMAX/XV(2))**2
      FBDMIN = 2.85 + 0.01*SL + SL**2/48000.0
      D = SL/XV(4)
   92 CB = 0.977 + 0.016*XV(2) + 0.076*(XV(2)**2) - 0.115*(XV(2)**3)
   93 CV = 35.0 * XV(1)/(SL**3)
   94 CD = CV * XV(5)
   95 T = SQRT(35.0*XV(1)/(SL*XV(3)*CB))
      IF(TMAX - T)129,96,96
   96 P = XV(3) * T
   97 FBDACT = P - T - 0.25
      IF(FBDACT - FBDMIN)129,99,99
   98 D = SL/XV(4)
      GO TO 97
   99 CALL DESIGN(NERR)
      IF(NERR)129,100,129
C BOX 10
  100 CALL COST
      CALL EFFECT(NERR)
      IF (NERR)129,101,129
  101 K1 = K1 + 1
      IF(CSTAR - CSTEFF)150,110,110
C BOX 11
  110 CSTAR = CSTEFF
      CALL OUTPUT(2,L)
      DO 111 IJ=1,5
      XB(IJ) = XV(IJ)
```

```
 111  CONTINUE
      GO TO 150
C BOX 12
 129  CONTINUE
      XV(I) = XSAVE
      SL = (VMAX/XV(2))**2
      D = SL/XV(4)
      CM = 0.977 + 0.018*XV(2) + 0.076*(XV(2)**2) - 0.115*(XV(2)**3)
      CV = 35.0 * XV(1)/(SL**3)
      CB = CM * XV(5)
      T = SQRT(35.0*XV(1)/(SL*XV(3)*CB))
      B = XV(3) * T
      IF(L - 1)140,140,150
C BOX 14
 140  IF(I - 5)150,141,141
 141  IF(IJ)170,170,150
C BOX 15
 150  CONTINUE
C BOX 16
      DO 160 IJ = 1,5
      XV(IJ) = XB(IJ)
 160  CONTINUE
      SL = (VMAX/XV(2))**2
      D = SL/XV(4)
      CM = 0.977 + 0.018*XV(2) + 0.076*(XV(2)**2) - 0.115*(XV(2)**3)
      CV = 35.0 * XV(1)/(SL**3)
      CB = CM * XV(5)
      T = SQRT(35.0*XV(1)/(SL*XV(3)*CB))
      B = XV(3) * T
      CALL DESIGN(NERR)
      CALL COST
      CALL OUTPUT(3,L)
      GO TO 200
C BOX 17
 170  CALL OUTPUT(1,L)
 200  CONTINUE
      END
```

```
      FUNCTION RAND(X)
      IF(X)10,20,20
10    IRAND = 0
      RAND = 0.5
      RETURN
20    IF(IRAND)30,30,40
30    R2 = 7**13
      R5 = 10**10
      RAND = 0.5
      IRAND = 1
      RETURN
40    R1 = R2*RAND
      R4 = AMOD(R1,R5)
      RAND = R4/R5
      RETURN
      END
```

```
      SUBROUTINE INPUT
      DIMENSION CR(6210), CS(3), CSTWG(7), E(8), FLDIS(2), IM(4),
     1MEXP(4), PC(3), TIME(4), VBAL(2), W(8), WTGPLS(7), XB(5),
     2XMAX(5), XMIN(5), XV(5)
      COMMON/I/ IM, K1, MEXP, MODE, MODEP, N, NCPO, NEM, NOFF
      COMMON/R/ AN, ARMMNT, B, BM, BMARG, BOLPUL, CANDE, CB, CHGS, CM,
     1CPO, CR, CS, CST, CSTEFF, CSTWG, CV, CWP, D, DIST, DRAFT, DMARG,
     2E, EHP, EM, ENDUR, ENGSPL, FBDACT, FLDIS, FOAM, FUELWT, GAS, GFM,
     3GMACT, OFF, OILLUB, PC, PROVS, RKB, RKG, SHP, SHPEND, SHPINS, SL,
     4SSB1, STORES, SALVG, T, TIME, TMAX, TOWPUL, TOWRES, VAMMO, VBAGS,
     5VBAL, VBERTH, VFAN, VFUEL, VGRDTK, VHD, VKTS, VLKRS, VLUBE, VMACH,
     6VMAX, VMESS, VOFFSP, VOL, VPASSG, VSALVS, VSHOPS, VSTRGR, VSTRS,
     7VTOW, VWATER, W, WATER, WETSUR, WTAMMO, WTGPLS, WTLS, WTLSM, XB,
     8XMAX, XMIN, XSGM, XSVOL, XV
      READ(5,9)(CR(I),I=1,6210)
    9 FORMAT(21X,6F7.3)
      READ(5,10)N,(TIME(I),I=1,4),(MEXP(J),J=1,4)
   10 FORMAT(I4,1X,4(F5.3,5X),4(I2,3X))
      DO 12 I1 = 1,5
      READ(5,11)XMIN(I1),XMAX(I1),XB(I1)
   11 FORMAT(15X,3(F10.5,5X))
   12 CONTINUE
      READ(5,13)TMAX,DIST
   13 FORMAT(5X,F5.2,10X,F10.2)
      READ(5,14)VMAX,PC(1),VKTS,PC(2),VTOW,PC(3)
   14 FORMAT(5X,F5.2,5X,F5.3)
      READ(5,15)MODEP,TOWRES,SHPINS
   15 FORMAT(4X,I1,2(5X,F10.2))
      READ(5,16)ARMMNT,WTAMMO,VAMMO
   16 FORMAT(5X,3(5X,F10.2))
      READ(5,17)MODE,(W(K),K=1,8)
   17 FORMAT(4X,I1,8F5.1)
      AN = N
      DO 18  I2 = 1,4
      IM(I2) = AN*TIME(I2) + 0.1
   18 CONTINUE
      WRITE(6,20)
   20 FORMAT(1H1,32X,'SALVAGE TUG OPTIMIZATION'/41X,'PAGE 1'/)
      WRITE(6,21)N,(IM(I),MEXP(I),I=1,4)
   21 FORMAT(9X,'THIS TRIAL WAS MADE USING ',I4,' LOOPS IN THE EXPONENTI
     1AL RANDOM SEARCH.'/9X,'THE NUMBER OF LOOPS AND UPDATING EXPONENT C
     2HANGES WERE AS FOLLOWS -'//24X,'FIRST',I4,' LOOPS      EXPONENT =',
     3I2,/25X,'NEXT',I4,' LOOPS      EXPONENT =',I2,/25X,'NEXT',I4,
     4' LOOPS      EXPONENT =',I2,/25X,'LAST',I4,' LOOPS      EXPONENT =',
     5I2,//)
      WRITE(6,22)(XMIN(I),XMAX(I),XB(I),I=1,5)
   22 FORMAT(9X,'THE PARAMETERS CONTROLLING THE SEARCH WERE -'//40X,
     1'MINIMUM',8X,'MAXIMUM',8X,'INITIAL'/9X,'DISPLACEMENT',17X,F9.3,
     26X,F9.3,6X,F9.3/9X,'SPEED-LENGTH RATIO',11X,3(F9.3,6X)/9X,'BEAM-TO
     3-DRAFT RATIO',10X,3(F9.3,6X)/9X,'LENGTH-TO-DEPTH RATIO',8X,3(F9.3,
     46X)/9X,'PRISMATIC COEFFICIENT',8X,3(F9.3,6X)//)
      WRITE(6,23)TMAX,DIST,VKTS,VMAX,PC(1),VKTS,PC(2),VTOW,PC(3)
   23 FORMAT(9X,'THE OPERATING CHARACTERISTICS SPECIFIED WERE -'//9X,
```

```
     1'MAXIMUM ALLOWABLE DRAFT = ',F4.1,' FEET'/9X,'REQUIRED ENDURANCE =
     2 ',F7.1,' NAUTICAL MILES AT ',F4.1,' KNOTS'//9X,'THE SPEED REQUIRE
     3MENTS WERE -'/26X,'SPEED',8X,'PROP. COEFF.'/9X,'MAXIMUM',8X,F4.1,
     4' KNOTS',8X,F5.3/9X,'ENDURANCE',6X,F4.1,' KNOTS',8X,F5.3/9X,
     5'TOWING',9X,F4.1,' KNOTS',8X,F5.3//)
      WRITE(6,24)TOWRES
   24 FORMAT(9X,'THE TOW RESISTANCE SPECIFIED WAS ',F8.1,' POUNDS'/)
      IF(MODEP)25,25,27
   25 WRITE(6,26)
   26 FORMAT(9X,'NO RESTRICTION WAS PLACED ON MAXIMUM INSTALLED SHP'//)
      GO TO 29
   27 WRITE(6,28)SHPINS
   28 FORMAT(9X,'THE INSTALLED POWER SPECIFIED WAS ',F6.1,' SHP'//)
   29 WRITE(6,30)ARMMNT,WTAMMO,VAMMO
   30 FORMAT(9X,'THE ARMAMENT REQUIREMENTS WERE -'//9X,'ARMAMENT WEIGHT
     1= ',F5.2,' TONS'/9X,'AMMUNITION WEIGHT = ',F4.1,' TONS'/9X,
     2'AMMUNITION VOLUME =',F5.0,' CUBIC FEET'//)
      WRITE(6,31)(W(K),K=1,8)
   31 FORMAT(9X,'THE WEIGHTING FACTORS FOR THE EFFECTIVENESS CALCULATION
     1 WERE -'//9X,'ENDURANCE',11X,F5.1/9X,'TOWING PULL',9X,F5.1/9X,
     2'DECK AREA AFT',7X,F5.1/9X,'BOLLARD PULL',8X,F5.1/9X,'BALLAST',
     313X,F5.1/9X,'SHIP DRAFT',10X,F5.1/9X,'EXCESS VOLUME',7X,F5.1/9X,
     4'EXCESS STABILITY',4X,F5.1/)
      IF(MODE - 1)32,34,36
   32 WRITE(6,33)
   33 FORMAT(9X,'NO PENALTY WAS ASSIGNED FOR EXCESS ENDURANCE OR TOWING
     1PULL')
      RETURN
   34 WRITE(6,35)
   35 FORMAT(9X,'A PENALTY WAS ASSIGNED IF ENDURANCE EXCEEDED THAT REQUI
     1RED')
      RETURN
   36 IF(MODE - 2)37,37,39
   37 WRITE(6,38)
   38 FORMAT(9X,'A PENALTY WAS ASSIGNED IF EXCESS TOWING PULL WAS SUPPLI
     1ED')
      RETURN
   39 WRITE(6,40)
   40 FORMAT(9X,'A PENALTY WAS ASSIGNED FOR EXCESS ENDURANCE AND EXCESS
     1TOWING PULL')
      RETURN
      END
```

```
      SUBROUTINE DESIGN(NERR)
      DIMENSION CR(6210), CS(3), CSTWG(7), E(8), FLDIS(2), IM(4),
     1MEXP(4), PC(3), TIME(4), VBAL(2), W(8), WTGPLS(7), XB(5),
     2XMAX(5), XMIN(5), XV(5)
      COMMON/I/ IM, K1, MEXP, MODE, MODEP, N, NCPO, NEM, NOFF
      COMMON/R/ AN, ARMMNT, B, BM, BMARG, BOLPUL, CANDE, CB, CHGS, CM,
     1CPO, CR, CS, CST, CSTEFF, CSTWG, CV, CWP, D, DIST, DKAFT, DMARG,
     2E, EHP, EM, ENDUR, ENGSPL, FBDACT, FLDIS, FCAM, FUELWT, GAS, GFM,
     3GMACT, OFF, OILLUB, PC, PROVS, RKB, RKG, SHP, SHPEND, SHPINS, SL,
     4SSB1, STORES, SALVG, T, TIME, TMAX, TOWPUL, TOWRES, VAMMO, VBAGS,
     5VBAL, VBERTH, VFAN, VFUEL, VGRDTK, VHD, VKTS, VLKRS, VLUBE, VMACH,
     6VMAX, VMESS, VOFFSP, VOL, VPASSG, VSALVS, VSHOPS, VSTRGR, VSTRS,
     7VTOW, VWATER, W, WATER, WETSUR, WTAMMO, WTGPLS, WTLS, WTLSM, XB,
     8XMAX, XMIN, XSGM, XSVOL, XV
      REAL LOADS
C BOX 1
      NERR = 0
C BOX 2  COMPUTE CUBIC NUMBER
      CUBIC = SL * B * D/100.
C BOX 5  WHAT TYPE POWERING CALCULATION
   50 IF(MODEP)999,60,90
C BOX 6  CALCULATE S.H.P. AT MAX SPEED AND TOWING SPEED
   60 CALL POWER(VMAX,PC(1),SHP1)
      CALL POWER(VTOW,PC(3),SHP)
      TOWPOW = TOWRES * VTOW * 1.689/550.0
      SHP2 = SHP + TOWPOW
      IF(SHP2 - SHP1)70,70,71
C BOX 7  INSTALLED POWER IS THE MAXIMUM OF ABOVE POWERS
   70 SHP = SHP1
      GO TO 80
   71 SHP = SHP2
C BOX 8  CALCULATE ENDURANCE POWER
   80 CALL POWER(VKTS,PC(2),SHPEND)
      TOWPUL = (SHP - SHP2 + TOWPOW)*550.0/(1.689*VTOW)
      GO TO 110
C BOX 9  CALCULATE S.H.P. AT ENDURANCE SPEED IF MAX S.H.P. IS INPUT
   90 CALL POWER(VKTS,PC(2),SHPEND)
      IF(SHPEND - SHPINS)100,100,999
C BOX 10 COMPUTE ACTUAL TOWLINE PULL
  100 CALL POWER(VTOW,PC(3),SHP1)
      SHP2 = SHPINS - SHP1
      TOWPUL = SHP2 * 550.0/(1.689 * VTOW)
      SHP = SHPINS
C BOX 11 CALCULATE LIGHT SHIP WEIGHTS WITHOUT MARGINS
  110 WTGPLS(1) = 0.3*CUBIC
      WTGPLS(2) = 54.0*(SHP/1000.0)**0.8
      SG300 = 0.00555*SHP
      SG301 = 0.135*(SHP/1000.0)**2
      SG3023 = 0.00264*CUBIC + 0.002035*CUBIC**2/1000.0
      ST3 = SG300 + SG301 + SG3023
      SG3501 = 0.00189*ST3**2
      WTGPLS(3) = ST3 + SG3501
      WTGPLS(4) = SG3023 - 0.00264*CUBIC
```

```
      WTGPLS(5) = 380.0 + 0.031*CUBIC + SHP/90.0
      WTGPLS(6) = 135.0 + 0.063*CUBIC
      WTGPLS(7) = ARMMNT
      WTLS = WTGPLS(1) + WTGPLS(2) + WTGPLS(3) + WTGPLS(4) + WTGPLS(5)
     1 + WTGPLS(6) + WTGPLS(7)
C BOX 12 COMPUTE FULL LOAD DISPLACEMENT LESS MARGIN
C        ESTIMATE CREW SIZE
 120  CREW = 36.3 + 0.00347*CUBIC*(SHP/1000.0)
      TEMP = 1.075*WTLS + 1.221*CREW + 140.0 + WTAMMO
      IF(XV(1) - TEMP)999,999,121
 121  NOFF = 0.084*CREW + 0.5
      NCPO = 0.063*CREW + 0.5
      NEM = 0.853*CREW + 0.5
      OFF = NOFF
      CPO = NCPO
      EM = NEM
      CREW = OFF + CPO + EM
C        COMPUTE WEIGHT OF CREW AND EFFECTS
      CANDE = (OFF*400.0 + CPO*330.0 + EM*230.0)/2240.0
C        COMPUTE WEIGHT OF PROVISIONS AND STORES
      CDT = CREW*60.0/2240.0
      DRY = 3.0*CDT
      FREEZE = 1.3*CDT
      CHILL = 1.12*CDT
      SHIPST = 1.13*CDT
      STSMED = 0.17*CDT
      SMLSTS = 0.13*CDT
      PROVS = DRY + FREEZE + CHILL + SHIPST + STSMED + SMLSTS
      GENSTS = 1.06*CDT
      ELNSTS = 0.035*WTGPLS(4)
      REPSTS = 0.005*WTLS
      STORES = GENSTS + ELNSTS + REPSTS
      WATER = 0.926*CREW
      OILLUB = 0.0025*SHP
C        COMPUTE SALVAGE WEIGHTS
      FOAM = 8.25
      GAS = 14.75
      SALVG = 102.3
      LOADS = STORES + WATER + OILLUB + FOAM + GAS + SALVG + PROVS
      FLDIS(1) = WTLS + CANDE + LOADS + WTAMMO
C BOX 13 COMPUTE MARGINS
      BMARG = 0.01*WTLS
      DMARG = 0.04*WTLS
      CHGS = 0.012*WTLS
      GFM = 0.008*WTLS
C        ADD MARGIN WEIGHT TO FULL LOAD DISPLACEMENT
      FLDIS(2) = FLDIS(1) + BMARG + DMARG + CHGS + GFM
C BOX 14   COMPUTE WEIGHT AVAILABLE FOR FUEL
      FUELWT = XV(1) - FLDIS(2)
      IF(FUELWT)999,999,160
C BOX 16 ESTIMATE INTERNAL VOLUME OF HULL
 160  AM = CM*B*T
      AMI = AM + (D-T)*B
```

```
      VOL = CB*CUBIC*100.0*SQRT(AMI/A[illegible])
C          ADD SUPERSTRUCTURE INTERNAL VOLUME
      IF(SL - 150.0)161,161,162
 161  SSB1 = B
      SSB2 = SSB1 - 6.0
      GO TO 163
 162  SSB1 = 150.0*B/SL
      SSB2 = SSB1 - 6.0
 163  VOL = VOL + (SL/4.0)*((SSB1 + SSB2)/2.0)*16.0
C BOX 17
C         COMPUTE MACHINERY AND AUXILIARY SPACE REQUIREMENTS
      DIESEL = SHP/4.0
      IF(DIESEL - 1200.0)171,171,172
 171  ENGL = 3.5 + 0.01385*DIESEL
      BREQ = 32.67
      IF(B - BREQ)173,174,174
 172  ENGL = 13.4 + 0.00571*DIESEL
      BREQ = 38.0
      IF(B - BREQ)173,174,174
 173  ENGSPL = 2.0*(ENGL + 14.0)
      GO TO 175
 174  ENGSPL = ENGL + 14.0 + 0.1*SL
 175  VMACH = (D - 4.0)*B*ENGSPL
C         COMPUTE VOLUME REQUIRED BY LIQUIDS
      VFUEL = FUELWT*43.0/0.95
      VWATER = WATER*36.0
      VLUBE = OILLUB*39.0/0.95
      VLIQ = VFUEL + VWATER + VLUBE
      TEMP = VMACH + VLIQ + VAMMO + 75000.0 + 200.0*CREW + 39.0*SL +
     1 815.0*CDT + 0.8*WTLS
      IF(VOL - TEMP)999,999,179
 179  VDRY = 60.0*DRY
      VFRZ = 57.0*FREEZE
      VCHILL = 68.0*CHILL
      VSHST = 66.0*SHIPST
      VMED = 6[illegible].0*ST[illegible]MED
      VSMLST = 173.0*[illegible]LSTS
      VGENST = 125.0*GEN[illegible]TS
      VELNST = 69[illegible].9*ELNSTS
      VREPST = 111.[illegible]*REPSTS
      VSTRS = (VDRY + VFRZ + VCHILL + VSHST + V[illegible] + VSMLST + VGE[illegible] +
     1 VELNST + VREPST)/0.7
      VSALVS = 34450.0
C         COMPUTE BERTHING REQUIREMENTS
      VOFFSR = (2.0*107.0 + 45.0*(OFF - 2.0))*8.0
      VCPORK = 26.0*CPO*8.5
      NEMB = 1.05*EM + 0.5
      EMB = NEMB
      VEMBR = 16.0*EMB*8.5
      VBERTH = VOFFSR + VCPORK + VEMBR
C         COMPUTE SANITARY FACILITY [illegible] REQUIREMENTS
      VOFFHD = 120.0*8.0
      VCPOHD = 50.0*8.0
```

```
      NWC = EMB/23.0 + 1.0
      NUR = EMB/40.0 + 1.0
      NLAV = EMB/15.0 + 1.0
      NSH = EMB/30.0 + 1.0
      HD = NWC + NUR + NLAV + NSH
      VEMHD = 17.5*HD*8.5
      VHD = VOFFHD + VCPOHD + VEMHD
C        COMPUTE MESSING SPACE VOLUME REQUIREMENTS
      NWRM = 0.7*OFF + 1.0
      NCPOM = 0.65*CPO + 1.0
      NEMM = 0.3*EMB + 1.0
      VWRM = 20*NWRM*8
      VCPOM = 15*NCPOM*8
      VEMM = 10*NEMM*8
      GALLEY = 3.0*CREW*8.5
      PANTRY = 800.0
      VMESS = VWRM + VCPOM + VEMM + GALLEY + PANTRY
      VBAGS = (1.5*OFF + 0.5*(CPO + EM))*8.5
C        COMPUTE OFFICE SPACE AND FACILITY VOLUMES
      VSKBAY = 1275.0
      VOFFCS = 2400.0
      VOPSSP = 4480.0
      VSERVS = 2125.0
      VCOS = 200.0
      VOFFSP = VSKBAY + VOFFCS + VOPSSP + VSERVS + VCOS
C        COMPUTE VOLUME OF PASSAGES
      VPASSG = (SL/4.0 + SSB1 + SSB2)*24.0 + 1.25*SL*25.5
C        COMPUTE AIR CASING AND FAN ROOM VOLUMES
      VFAN = 0.194*SHP*8.5
C        VOLUME OF FOUL WEATHER GEAR, DECK GEAR, CLEANING GEAR AND
C        LINEN LOCKERS
      VLKRS = 1280.0
C        COMPUTE VOLUME OF STEERING GEAR ROOM
      VSTRGR = (SL/12.0)*0.035*B*9.0
C        SHOP VOLUMES
      VDIVSH = 5100.0
      VSALSH = 7225.0
      VMISSH = 8075.0
      VSHOPS = VDIVSH + VSALSH + VMISSH
C        VOLUME REQUIRED BY GROUND TACKLE
      VGRDTK = 2915.0
      VWINDL = 3315.0
      VGRDTK = VGRDTK + VWINDL
C        COMPUTE BALLAST REQUIREMENTS
      VBAL(1) = 0.1*WTLS*35.0
C        COMPUTE TOTAL VOLUME REQUIRED
      VOLREQ = VSTRS + VSALVS + VBERTH + VHD + VMESS + VBAGS + VOFFSP +
     1 VPASSG + VFAN + VLKRS + VSTRGR + VSHOPS + VGRDTK + VLIQ + VMACH
     2 + VAMMO
      VBAL(2) = VOL - VOLREQ
      IF(VBAL(2) - VBAL(1))177,176,176
  176 XSVOL = VBAL(2) - VBAL(1)
      VBAL(2) = VBAL(1)
```

```
      GO TO 180
 177  XSVOL = 0.0
      IF(VBAL(2))999,180,180
C BOX 18 IS STABILITY ADEQUATE
C         FIND VERTICAL CENTER OF GRAVITY
 180  VRTMOM = D*(0.74*WTGPLS(1) + 0.5*WTGPLS(2) + 0.791*WTGPLS(3) +
     1 1.053*WTGPLS(5) + WTGPLS(7)) + (D + 4.5)*WTGPLS(4) + (D + 2.0)*
     2 WTGPLS(6)
      RKG = VRTMOM/WTLS
      VRTMOM = VRTMOM + (BMARG + DMARG + CHGS + GFM)*RKG
     1 + 0.405*D*(CANDE + LOADS + FUELWT)
      RKG = VRTMOM/XV(1)
C         COMPUTE WATERPLANE COEFFICIENT
      CWP = 1.136 + XV(5)*(1.75*XV(5) - 1.7)
C         FIND VERTICAL CENTER OF BUOYANCY
      RKB = (2.5*T - 35.0*XV(1)/(CWP*SL*B))/3.0
C         FIND BM
      BM = CWP*(0.0727*CWP + 0.0106)*SL*B**3/(35.0*XV(1))
C         COMPUTE ACTUAL GM
      GMACT = RKB + BM - RKG
C     ASSUME REQUIRED GM (UNCORRECTED FOR FREE SURFACE) IS ONE-TENTH OF
C         THE SHIP BEAM
      XSGM = GMACT - 0.1*B
      IF(XSGM)999,190,190
C BOX 19 COMPUTE ENDURANCE
 190  ENDUR = FUELWT*24.0*VKTS/(0.00375*SHPEND)
C BOX 20 COMPUTE BOLLARD PULL
      BOLPUL = 25.0*SHP
C BOX 21 COMPUTE AMOUNT OF CLEAR DECK AREA AFT
      DKAFT = SL*B/3.0
      WTLSM = WTLS + BMARG + DMARG + CHGS + GFM
      GO TO 1000
C         SET ERROR CODE IF ERROR ENCOUNTERED IN SUBROUTINE
 999  NERR = 1
1000  RETURN
      END
```

```
      SUBROUTINE POWER(V,PCI,SHPOUT)
      DIMENSION CR(6210), CS(3), CSTWG(7), E(8), FLDIS(2), IM(4),
     1MEXP(4), PC(3), TIME(4), VBAL(2), W(8), WTGPLS(7), XB(5),
     2XMAX(5), XMIN(5), XV(5)
      COMMON/I/ IM, K1, MEXP, MODE, MODEP, N, NCPO, NEM, NOFF
      COMMON/R/ AN, ARMMNT, B, BM, BMARG, BOLPUL, CANDE, CB, CHGS, CM,
     1CPO, CR, CS, CST, CSTEFF, CSTWG, CV, CWP, D, DIST, DKAFT, DMARG,
     2E, EHP, EM, ENDUR, ENGSPL, FBDACT, FLDIS, FOAM, FUELWT, GAS, GFM,
     3GMACT, OFF, OILLOW, PC, PROVS, RKS, RK3, SHP, SHPEND, SHPINS, SL,
     4SSB1, STORES, SALVG, T, TIME, TMAX, TOWPUL, TOWRES, VAMMO, VBAGS,
     5VBAL, VBERTH, VFAN, VFUEL, VGRDTK, VHD, VKTS, VLKRS, VLUBE, VMACH,
     6VMAX, VMESS, VOFFSP, VOL, VPASSG, VSALVS, VSHOPS, VSTRGR, VSTRS,
     7VTOW, VWATER, W, WATER, WETSUR, WTAMMO, WTGPLS, WTLS, WTLSM, XB,
     8XMAX, XMIN, XSGM, XSVOL, XV
      XPFF(II,JJ,KK) = 23*15*(II-1) + 15*(JJ-1) + KK
      XPPFF(II,JJ,KK) = 1035 + XPFF(II,JJ,KK)
      CONTINUE
      VL = V/SQRT(SL)
      IF(VL - 0.5)1,2,2
    1 VL = 0.5
C           COMPUTATION OF RESIDUAL RESISTANCE
    2 CVV = CV*1000.0
      IF(CVV-2.0)89,90,90
   89 MMM = 0
      CVD = CVV-1.0
      GO TO 4
   90 IF(CVV-3.0)91,92,92
   91 MMM = 1
      CVD = CVV - 2.0
      GO TO 4
   92 IF(CVV-4.0)93,94,94
   93 MMM = 2
      CVD = CVV - 3.0
      GO TO 4
   94 IF(CVV-5.0)95,96,96
   95 MMM = 3
      CVD = CVV - 4.0
      GO TO 4
   96 MMM = 4
      CVD = CVV - 5.0
    4 IF(XV(3)/2.0 - 1.0)7,8,8
    7 I = 1
      GO TO 9
    8 I = 2
    9 LL = 100.0*XV(5)
      ALL = LL
      AL = 100.0*XV(5) - ALL
      IF(AL-0.5)10,11,11
   10 J = LL - 47
      GO TO 12
   11 J = LL - 46
   12 K = 20.0*(VL + 0.05) - 9.0
      L = XPFF(I,J,K)
```

```
      L = L + 1035*MMM
      AA = CR(L)
      L = XPPFF(I,J,K)
      L = L + 1035*MMM
      BB = CR(L)
      L = XPFF(I+1,J,K)
      L = L + 1035*MMM
      CC = CR(L)
      L = XPPFF(I+1,J,K)
      L = L + 1035*MMM
      DD = CR(L)
      L = XPFF(I,J,K-1)
      L = L + 1035*MMM
      EE = CR(L)
      L = XPPFF(I,J,K-1)
      L = L + 1035*MMM
      FP = CR(L)
      L = XPFF(I+1,J,K-1)
      L = L + 1035*MMM
      GG = CR(L)
      L = XPPFF(I+1,J,K-1)
      L = L + 1035*MMM
      HH = CR(L)
      ABB = (BB-AA)*CVD + AA
      ACC = (DD-CC)*CVD + CC
      ADD = (FP-EE)*CVD + EE
      AEE = (HH-GG)*CVD + GG
      IF(XV(3)-3.0)23,24,24
   23 BHD = XV(3) - 2.25
      GO TO 25
   24 BHD = XV(3) - 3.0
   25 BAA = (ACC-ABB)*BHD/0.75 + ABB
      BBB = (AEE-ADD)*BHD/0.75 + ADD
      AK = K
      VLR = 0.45 + AK*0.05
      VLD = VLR - VL
      CRINT = BAA - (BAA-BBB)*VLD/0.05
      ACRINT = CRINT/1000.0
C           COMPUTE WETTED SURFACE COEFFICIENT
      CS1 = 15.086
      CS2 = 15.046
      CS3 = 15.115
      CS4 = 15.293
      IF(XV(3)-2.75)66,67,68
   66 ABH = 2.75 - XV(3)
      CWS = CS2 - ((CS2-CS1)*ABH)/0.5
      GO TO 69
   67 CWS = CS2
      GO TO 69
   68 IF(XV(3)-3.25)76,77,78
   76 ABH = 3.25 - XV(3)
      CWS = CS3 - ((CS3-CS2)*ABH)/0.5
      GO TO 69
```

```
 77   CWS = CS3
      GO TO 69
 78   ABH = 3.75 - XV(3)
      CWS = CS4 - ((CS4-CS3,*ABH)/0.5
C            COMPUTE SHP REQUIRED
 69   RE = 131778.0*V*SL
      FRE = ALOG10(RE) - 2.0
      CFS = 0.075/(FRE**2)
      CF = CFS + 0.0004
      ACT = CF + ACRINT
      FK1 = 1.25*1.03/PCI
      CON = FK1*V**3*CWS*0.0087184*SQRT(SL*XV(1))
      SHPOUT = CON*ACT
      EHP = SHPOUT/(FK1)
      WETSUR = CWS*SQRT(XV(1)*SL)
      RETURN
      END
```

```
      SUBROUTINE COST
      DIMENSION CR(6210), CS(3), CSTWG(7), E(5), FLDIS(2), IM(4),
     1MEXP(4), PC(3), TIME(4), VBAL(2), W(8), WTGPLS(7), XB(5),
     2XMAX(5), XMIN(5), XV(5)
      COMMON/I/ IM, K1, MEXP, MODE, MODEP, N, NCPC, NEM, NOFF
      COMMON/R/ AN, ARMMNT, B, BM, BMARG, BULPUL, CANDE, CB, CHGS, CM,
     1CPO, CR, CS, CST, CSTEFF, CSTWG, CV, CWP, D, DIST, DRAFT, DMARG,
     2E, EHP, EM, ENDUR, ENGSPL, FBDACT, FLDIS, FUEL, FUELAT, GAS, GFM,
     3GMACT, OFF, OILLUB, PC, PROVS, RRB, RRG, SHP, SHPEND, SHPINS, SL,
     4SSB1, STORES, SALVG, T, TIME, TMAX, TOWPUL, TOWRES, VAMMO, VBAGS,
     5VBAL, VBERTH, VFAN, VFUEL, VGRDIK, VHD, VKTS, VLKRS, VLUBE, VMACH,
     6VMAX, VMESS, VOFFSP, VOL, VPASSG, VSALVS, VSHOPS, VSTRGR, VSTRS,
     7VTOW, VWATER, W, WATER, WETSUR, WTAMMO, WTGPLS, WTLS, WTLSM, XB,
     8XMAX, XMIN, XSGM, XSVOL, XV
C BOX 1    COMPUTE COSTS BY WEIGHT GROUPS
      CSTWG(1) = 0.002*WTGPLS(1)
      CSTWG(2) = 0.006*WTGPLS(2)
      CSTWG(3) = 0.008*WTGPLS(3)
      CSTWG(4) = 0.010*WTGPLS(4)
      CSTWG(5) = 0.004*WTGPLS(5)
      CSTWG(6) = 0.005*WTGPLS(6)
      CSTWG(7) = 0.010*WTGPLS(7)
      CST = CSTWG(1) + CSTWG(2) + CSTWG(3) + CSTWG(4) + CSTWG(5) +
     1 CSTWG(6) + CSTWG(7)
C BOX 2    ADD COST FOR MARGIN
      CST = 1.07*CST
C BOX 3    ADD DESIGN AND CONSTRUCTION COST
      CST = 1.08*CST
C BOX 4    ALLOW FOR ESCALATION
      CST = 1.03*CST
C BOX 5    ADD PROFIT AT 7 PER-CENT
      CST = 1.07*CST
C BOX 6    ALLOWANCE FOR CHANGES
      CST = 1.01*CST
C BOX 7    ALLOWANCE FOR POST DELIVERY
      CST = 1.005*CST
C BOX 8    ALLOWANCE FOR QUALITY ASSURANCE
      CST = 1.[illegible]1*CST
C BOX 9    ALLOWANCE FOR SHOCK REQUIREMENTS
      CS(1) = 1.[illegible]*CST
C BOX 10   ANNUAL CREW WAGES
      CS(2) = 0.015*OFF + 0.01*CPO + 0.[illegible]
C BOX 11   COMPUTE MAINTENANCE AND REPAIR COSTS
      CS(3) = 0.20[illegible]5*(XV(1)/1000. )**0.[illegible]7095 + 0.[illegible]5*ALOG(SHP/3000.
     10) + 0.05
      TEMP = CS(2) + CS(3)
C BOX 12  COMPUTE PRESENT VALUE OF 25 YEARS OF MAINTENANCE AND REPAIR
C         AND OF CREW WAGES
      TEMP = 15.62208*TEMP
C BOX 13   PRESENT VALUE OF LIFE CYCLE COST
      CST = CS(1) + TEMP
      RETURN
      END
```

```
      SUBROUTINE EFFECT (NERR)
      DIMENSION CR(6210), CS(3), CSTWG(7), E(8), FLDIS(2), IM(4),
     1MEXP(4), PC(3), TIME(4), VBAL(2), W(8), WTGPLS(7), XB(5),
     2XMAX(5), XMIN(5), XV(5)
      COMMON/I/ IM, K1, MEXP, MODE, MODEP, N, NCPC, NEM, NOFF
      COMMON/R/ AN, ARMMNT, B, BM, BMARG, BOLPUL, CANDE, CB, CHGS, CM,
     1CPO, CR, CS, CST, CSTEFF, CSTWG, CV, CWP, D, DIST, DKAFT, DMARG,
     2E, EHP, EM, ENDUR, ENGSPL, FBDACT, FLDIS, FCAV, FUELWT, GAS, GFM,
     3GMACT, OFF, OILLUB, PC, PROVS, RKB, RKG, SHP, SHPEND, SHPINS, SL,
     4SSB1, STORES, SALVG, T, TIME, TMAX, TOWPUL, TOWRES, VAMMO, VBAGS,
     5VBAL, VBERTH, VFAN, VFUEL, VGRDTK, VHD, VKTS, VLKRS, VLUBE, VMACH,
     6VMAX, VMESS, VOFFSP, VOL, VPASSG, VSALVS, VSHOPS, VSTRGR, VSTRS,
     7VTOW, VWATER, W, WATER, WETSUR, WTAMMO, WTGPLS, WTLS, WTLSM, XB,
     8XMAX, XMIN, XSGM, XSVOL, XV
C BOX 1    INITIALIZE ERROR CODE
      NERR = 0
C BOX 2    CALCULATE INDIVIDUAL EFFECTIVENESSES
      E(1)=(ENDUR/DIST - 1.0)*15.1515*W(1)
      E(2)=(TOWPUL/TOWRES - 1.0)*10.8696*W(2)
      E(3)=(DKAFT/4000.0 - 1.0)*79.257*W(3)
      E(4)=(BOLPUL/896000.0 + 1.0)*.8954*W(4)
      E(5)=(VBAL(2)/VBAL(1) - 1.0)*1.814*W(5)
      E(6)=(1.0 - T/TMAX)*8.5793*W(6)
      E(7)=(XSVOL/34450.0)*1.838*W(7)
      E(8)=(XSGM/(GMACT-XSGM))*3.3402*W(8)
C BOX 3    ANY PENALTIES FOR EXCESS ENDURANCE OR TOW PULL
      IF(MODE - 1)30,31,32
   30 IF(ENDUR-DIST)40,40,33
   31 E(1) = -ABS(E(1))
      GO TO 40
   32 E(2) = -ABS(E(2))
      IF(MODE - 2)40,40,31
   33 E(1) = 0.0
C BOX 4    CALCULATE EFFECTIVENESS
   40 EFF = 100. + E(1) + E(2) + E(3) + E(4) + E(5) + E(6) + E(7) + E(8)
      IF(EFF - 0.1)60,50,50
C BOX 5    CALCULATE COST/EFFECT QUOTIENT
   50 CSTEFF = CST/EFF
      RETURN
   60 NERR = 1
      RETURN
      END
```

```
      SUBROUTINE OUTPUT(N1,L)
      DIMENSION CR(5210), CS(3), CSTWG(7), E(8), FLDIS(2), IM(4),
     1MEXP(4), PC(3), TIME(4), VBAL(2), W(8), WTGPLS(7), XB(5),
     2XMAX(5), XMIN(5), XV(5)
      COMMON/I/ IM, K1, MEXP, MODE, MODEP, N, NCPO, NEM, NOFF
      COMMON/R/ AN, ARMMNT, B, BM, BMARG, BOLPUL, CANDE, CB, CHGS, CM,
     1CPO, CR, CS, CST, CSTEFF, CSTWG, CV, CWP, D, DIST, DRAFT, DMARG,
     2E, EHP, EM, ENDUR, ENGSPL, FBDACT, FLDIS, FOAM, FUELWT, GAS, GFM,
     3GMACT, OFF, OILLUB, PC, PROVS, RKB, RKG, SHP, SHPEND, SHPINS, SL,
     4SSB1, STORES, SALVG, T, TIME, TMAX, TOWPUL, TOWRES, VAMMO, VBAGS,
     5VBAL, VBERTH, VFAN, VFUEL, VGRDTK, VHD, VKTS, VLKRS, VLUBE, VMACH,
     6VMAX, VMESS, VOFFSP, VOL, VPASSG, VSALVS, VSHOPS, VSTRGR, VSTRS,
     7VTOW, VWATER, W, WATER, WETSUR, WTAMMO, WTGPLS, WTLS, WTLSM, XB,
     8XMAX, XMIN, XSGM, XSVOL, XV
      GO TO (1,6,21),N1
    1 WRITE(6,2)
    2 FORMAT(1H1,32X,'SALVAGE TUG OPTIMIZATION'/)
      WRITE(6,3)
    3 FORMAT(9X,'THE PROGRAM HAS EVALUATED A DESIGN BASED ON THE SET OF
     1INITIAL VARIABLE'/9X,'VALUES PROVIDED AS INPUT PLUS TWENTY-FOUR AD
     2DITIONAL RANDOM DESIGNS AND'/9X,'FOUND NO ACCEPTABLE INITIAL SOLUT
     3ION. THE VALUES OF THE ITEMS CALCULATED FOR'/9X,'THE LAST SET OF R
     4ANDOM VARIABLES ARE LISTED BELOW - ZERO VALUES INDICATE'/9X,
     5'THAT THE ITEM WAS NOT REACHED FOR CALCULATION.'/)
      GO TO 8
    4 WRITE(6,5)
    5 FORMAT(9X,'RE-EVALUATE LIMITS ON VARIABLES AND INITIAL VARIABLE VA
     1LUES IN LIGHT OF'/9X,'THE ABOVE RESULTS.')
      RETURN
    6 WRITE(6,7)L
    7 FORMAT(1H1,32X,'SALVAGE TUG OPTIMIZATION'/40X,'LOOP',I4/)
    8 WRITE(6,9)(XV(I),I=1,5)
    9 FORMAT(9X,'VALUES OF RANDOM VARIABLES -'/12X,'FULL LOAD DISPLACEME
     1NT = ',F6.1,' TONS, SPEED-LENGTH RATIO = ',F5.3,','/12X,'BEAM-TO-D
     2RAFT RATIO = ',F5.3,', LENGTH-TO-DEPTH RATIO = ',F5.2,', PRISMATIC
     3'/12X,'COEFFICIENT = ',F4.3,'.'/)
      WRITE(6,10)SL,B,T,D,FBDACT
   10 FORMAT(9X,'SHIP DIMENSIONS -'/12X,'L.B.P.= ',F6.2,' FEET, BEAM = '
     1,F5.2,' FEET, DRAFT = ',F5.2,' FEET,'/12X,'DEPTH = ',F5.2,' FEET,
     2FREEBOARD = ',F5.2,' FEET'/)
      WRITE(6,11)XV(5),CM,CB,CV
   11 FORMAT(9X,'FORM COEFFICIENTS -'/12X,'PRISMATIC =',F4.3,', MIDSHIPS
     1 =',F5.3,', BLOCK =',F4.3,', VOLUMETRIC = ',F6.5/)
      WRITE(6,12)EHP,WETSUR,SHP,SHPEND
   12 FORMAT(9X,'RESISTANCE AND PROPULSION DATA -'/12X,'E.H.P.=',F7.1,
     1', WETTED SURFACE = ',F7.1,' SQUARE FEET,'/12X,'MAXIMUM S.H.P.= ',
     2F7.1,', ENDURANCE S.H.P.=',F7.1/)
      WRITE(6,13)(WTGPLS(I),I=1,7),WTLS
   13 FORMAT(9X,'WEIGHTS -'/12X,'GROUP 1   HULL STRUCTURE',8X,F7.2,
     1' TONS'/12X,'GROUP 2   PROPULSION',12X,F7.2,' TONS'/12X,'GROUP 3
     2 ELECTRIC PLANT',8X,F7.2,' TONS'/12X,'GROUP 4   COMM AND CONTROL',
     36X,F7.2,' TONS'/12X,'GROUP 5   AUXILIARY SYSTEMS',5X,F7.2,' TONS'/
     412X,'GROUP 6   OUTFIT AND FURN.',6X,F7.2,' TONS'/12X,'GROUP 7   AR
```

```
     5MARGINT',14X,F7.2,' TONS'/12X,'LIGHT SHIP DISPLACEMENT',9X,F7.2,
     6' TONS'/)
      WRITE(6,14)FUELWT,ENDUR
 14   FORMAT(9X,'FUEL =',F6.1,' TONS, RESULTING IN ENDURANCE = ',F7.1,
     1' NAUTICAL MILES.'/)
      WRITE(6,15)VOL,XSVOL
 15   FORMAT(9X,'VOLUME = ',F7.0,' CUBIC FEET. THE EXCESS VOLUME = ',
     1F6.0,' CUBIC FEET.'/)
      WRITE(6,16)RKG,RKB,BM,GMACT
 16   FORMAT(9X,'STABILITY DATA -'/12X,'KG = ',F5.2,' FEET, KB = ',F4.2,
     ' FEET, BM = ',F5.2,' FEET, GM =',F5.2,' FEET'/)
      WRITE(6,20)
 20   FORMAT(9X,'EFFECTIVENESSES -')
      WRITE(6,17)(E(K),W(K),K=1,8)
 17   FORMAT(12X,'ENDURANCE',9X,F7.3,7X,'WITH WEIGHT OF ',F4.1,3X/12X,
     1'TOWING PULL',7X,F7.3,6X,' WITH WEIGHT OF ',F4.1/12X,'DECK AREA AF
     2T',5X,F7.3,7X,'WITH WEIGHT OF ',F4.1/12X,'BOLLARD PULL',6X,F7.3,
     37X,'WITH WEIGHT OF ',F4.1/12X,'BALLAST',11X,F7.3,7X,'WITH WEIGHT O
     4F ',F4.1/12X,'SHIP DRAFT',8X,F7.3,7X,'WITH WEIGHT OF ',F4.1/12X,
     5'EXCESS VOLUME',5X,F7.3,7X,'WITH WEIGHT OF ',F4.1/ 12X,'EXCESS STA
     6BILITY  ',F7.3,7X,'WITH WEIGHT OF ',F4.1/)
      WRITE(6,18)CS(1),CST,CSTEFF
 18   FORMAT(9X,'COST -'/12X,'ACQUISITION COST = ',F9.6,' MILLION DOLLAR
     1S'/12X,'LIFE CYCLE COST = ',F10.6,' MILLION DOLLARS'//9X,'COST EFF
     2ECTIVENESS =',F7.4/)
      GO TO(4,19,19),N1
 19   RETURN
 21   WRITE(6,22)K1
 22   FORMAT(1H1,32X,'SALVAGE TUG OPTIMIZATION'///9X,'THE FOLLOWING DESI
     1GN WAS FOUND TO BE THE OPTIMUM OF THE',I5,' DESIGNS'/9X,'EVALUATED
     2 USING THE EXPONENTIAL RANDOM SEARCH OPTIMIZATION TECHNIQUE.'//)
      WRITE(6,23)SL,XV(5),NOFF,B,CM,NCPO,T,CB,NEN,D,CV,SSB1,CWP
 23   FORMAT(17X,'SHIP DIMENSIONS',12X,'FORM COEFFICIENTS',13X,'CREW'/
     115X,'L.B.P.',F8.2,' FEET',10X,'PRISMATIC',F8.3,9X,I2,' OFFICERS'/
     215X,'BEAM',F10.2,' FEET',10X,'MIDSHIPS',F9.3,9X,I2,' C.P.O.'/15X,
     3'DRAFT',F9.2,' FEET',10X,'BLOCK',F12.3,8X,I3,' ENLISTED'/15X,
     4'DEPTH',F9.2,' FEET',[illegible]'VOLUMETRIC',F[illegible]/[illegible]'S.S.B.R',F7.2,
     5' FEET',10X,'WATERPLANE',F[illegible].3//)
      WRITE(6,24)EHP,[illegible]
 24   FORMAT(15X,'E.H.P.=',F7.1,', MAXIMUM S.H.P.= ',F7.1,', ENDURANCE S
     1.H.P.=',F7.1/1[illegible]X,' [illegible] = ',F7.1,' SQUARE FEET'//)
      WRITE(6,25)(WTGPLS(I),I=1,7),WTLS,BMARG,DMARG,CHGS,GFM,WTLSM
 25   FORMAT(21X,'GROUP 1    HULL STRUCTURE',[illegible]X,F6.[illegible],' TONS'/21X,
     1'GROUP 2    PROPULSION',14X,F6.1,' TONS'/21X,'GROUP 3    ELECTRIC PL
     2ANT',10X,F6.1,' TONS'/21X,'GROUP 4    COMM AND CONTROL',8X,F6.1,
     3' TONS'/21X,'GROUP 5    AUXILIARY SYSTEMS',7X,F6.1,' TONS'/21X,
     4'GROUP 6    OUTFIT AND FURN.',8X,F6.1,' TONS'/21X,'GROUP 7    ARMAME
     5NT',16X,F6.1,' TONS'/21X,'LIGHT SHIP DISPL (W/O MARGINS)     ',F6.1
     6,' TONS'//21X,'BUILDERS MARGIN',19X,F6.1,' TONS'/21X,'DESIGN MARGI
     7N',21X,F6.1,' TONS'/21X,'CHANGE ORDERS',21X,F6.1,' TONS'/21X,
     8'GOVT FURNISHED MATERIAL',11X,F6.1,' TONS'/[illegible]X,'LIGHT SHIP DISPL (
     9WITH MARGINS)     ',F6.1,' TONS'/)
      WRITE(6,26)CAMDE,[illegible],GAS,
```

```
    1SALVG,XV(1)
26   FORMAT(21X,'SHIP OFFICERS, CREW AND EFFECTS    ',F6.1,' TONS'/21X,
    'SHIP AMMUNITION',19X,F6.1,' TONS'/21X,'PROVISIONS AND PERSONNEL S
    2TORES    ',F6.1,' TONS'/21X,'GENERAL STORES',20X,F6.1,' TONS'/21X,
    3'POTABLE WATER',21X,F6.1,' TONS'/21X,'LUBRICATING OIL, SHIP',13X,
    4F6.1,' TONS'/21X,'DIESEL OIL',24X,F6.1,' TONS'/21X,'FOAM LIQUID',
    523X,F6.1,' TONS'/21X,'GASES',29X,F6.1,' TONS'/21X,'SALVAGE EQUIPME
    6NT',17X,F6.1,' TONS'//21X,'FULL LOAD DISPLACEMENT',13X,F6.1,' TONS
    7'/25X,'(WITH MARGINS)'///)
     WRITE(6,27)
27   FORMAT(9X,'*  THIS IS THE BREADTH OF THE LOWER SUPERSTRUCTURE DECK
    1. THE UPPER DECK'/9X,'OF THE SUPERSTRUCTURE IS SIX FEET LESS IN BR
    2EADTH. THE SUPERSTRUCTURE IS'/9X,'ONE-QUARTER OF THE L.B.P. IN LEN
    3GTH.')
     WRITE(6,28)VOL,VSTRS,VSALVS,VBERTH,VMESS,VHD,VBAGS,VOFFSP,VPASSG,
    1VFAN,VLKRS,VSHOPS,VGRDTK,VSTRGR,VAMMO,VMACH,VFUEL,VWATER,VLUBE,
    2VBAL(2),XSVOL
28   FORMAT(1H1,41X,'VOLUMES'//21X,'TOTAL VOLUME AVAILABLE',11X,F7.0,
    1' CUBIC FEET'//21X,'PROVISIONS AND STORES VOLUME', 5X,F7.0,' CUBIC
    2 FEET'/21X,'SALVAGE STORES VOLUME',12X,F7.0,' CUBIC FEET'/21X,
    3'BERTHING SPACE VOLUME',12X,F7.0,' CUBIC FEET'/21X,'MESSING SPACE
    4VOLUME',13X,F7.0,' CUBIC FEET'/21X,'SANITARY SPACE VOLUME',12X,
    5F7.0,' CUBIC FEET'/21X,'BAGGAGE STOWAGE VOLUME',11X,F7.0,' CUBIC F
    6EET'/21X,'OFFICE SPACE VOLUME',14X,F7.0,' CUBIC FEET'/21X,'PASSAGE
    7WAY VOLUME',16X,F7.0,' CUBIC FEET'/21X,'FAN ROOM AND UPTAKE SPACE
    8VOLUME ',F7.0,' CUBIC FEET'/21X,'DECK GEAR AND MISC. LOCKERS VOL.'
    9,F8.0,' CUBIC FEET'/21X,'SHOP VOLUMES',21X,F7.0,' CUBIC FEET'/21X,
    1'WINDLASS ROOM AND CHAIN LKR VOL. ',F7.0,' CUBIC FEET'/21X,'STEERI
    1NG GEAR ROOM VOLUME',8X,F7.0,' CUBIC FEET'/21X,'AMMUNITION VOLUME'
    2,16X,F7.0,' CUBIC FEET'/21X,'MACHINERY SPACE VOLUME *',9X,F7.0,
    3' CUBIC FEET'/21X,'FUEL OIL TANK VOLUME',13X,F7.0,' CUBIC FEET'/
    421X,'FRESH WATER TANK VOLUME',10X,F7.0,' CUBIC FEET'/21X,'LUBE OIL
    5 TANK VOLUME',13X,F7.0,' CUBIC FEET'/21X,'BALLAST TANK VOLUME',
    614X,F7.0,' CUBIC FEET'/21X,'EXCESS VOLUME',20X,F7.0,' CUBIC FEET'/
    7/)
     WRITE(6,29)XKM,BM,XKG,GMACT,XSGM
29   FORMAT(39X,'STABILITY'//36X,'KM = ',F5.2,' FEET'/36X,'BM = ',F5.2,
    1' FEET'/36X,'KG = ',F5.2,' FEET'/36X,'GM = ',F5.2,' FEET'//32X,
    2'EXCESS GM ** = ',F5.2,' FEET'//)
     WRITE(6,30)TOWPUL,BOLPUL,DKAFT
30   FORMAT(37X,'MISCELLANEOUS'//29X,'TOWING PULL',F11.0,' POUNDS'/
    129X,'BOLLARD PULL',F10.0,' POUNDS'/29X,'DECK AREA AFT',F9.0,
    2' SQUARE FEET'//)
     WRITE(6,31)(CS(I),I=1,3),CST
31   FORMAT(42X,'COST'//21X,'ACQUISITION COST',5X,F9.6,' MILLION DOLLAR
    1S'/21X,'ANNUAL CREW COSTS     ',F9.6,' MILLION DOLLARS'/21X,'ANNUAL
    2 UPKEEP COST    ',F9.6,' MILLION DOLLARS'/21X,'LIFE CYCLE COST',6X,
    3F9.6,' MILLION DOLLARS'///)
     WRITE(6,32)ENGSPL
32   FORMAT(9X,'*  THE MACHINERY SPACE VOLUME WAS COMPUTED FROM A CALCU
    1LATED REQUIRED'/9X,'ENGINEERING SPACE LENGTH OF',F6.2,' FEET.'//
    29X,'**  THE EXCESS GM IS COMPUTED BY ASSUMING A REQUIRED GM (UNCOR
    3RECTED FOR'/9X,'FREE SURFACE) OF TEN PERCENT OF THE SHIPS BEAM')
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```
RETURN
END
```

APPENDIX F

This appendix contains a sample output for the case where no initial, feasible solution was found and a listing of a sample run in which the program selected an optimum design.

THIS TRIAL WAS MADE USING 1 LOOPS IN THE EXPONENTIAL RANDOM SEARCH.
THE NUMBER OF LOOPS AND UPDATING EXPONENT CHANGES WERE AS FOLLOWS -

FIRST	1 LOOPS	EXPONENT = 1
NEXT	0 LOOPS	EXPONENT = 3
NEXT	0 LOOPS	EXPONENT = 5
LAST	0 LOOPS	EXPONENT = 7

THE PARAMETERS CONTROLLING THE SEARCH WERE -

	MINIMUM	MAXIMUM	INITIAL
DISPLACEMENT	2500.000	3100.000	3000.000
SPEED-LENGTH RATIO	1.000	1.050	1.030
BEAM-TO-DRAFT RATIO	2.250	3.750	3.340
LENGTH-TO-DEPTH RATIO	9.000	14.000	11.000
PRISMATIC COEFFICIENT	0.480	0.650	0.570

THE OPERATING CHARACTERISTICS SPECIFIED WERE -

MAXIMUM ALLOWABLE DRAFT = 15.5 FEET
REQUIRED ENDURANCE = 10000.0 NAUTICAL MILES AT 13.0 KNOTS

THE SPEED REQUIREMENTS WERE -

	SPEED	PROP. COEFF.
MAXIMUM	17.2 KNOTS	0.680
ENDURANCE	13.0 KNOTS	0.750
TOWING	8.6 KNOTS	0.650

THE TOW RESISTANCE SPECIFIED WAS 153000.0 POUNDS

THE INSTALLED POWER SPECIFIED WAS 6000.0 SHP

THE ARMAMENT REQUIREMENTS WERE -

ARMAMENT WEIGHT = 2.44 TONS
AMMUNITION WEIGHT = 11.2 TONS
AMMUNITION VOLUME = 500. CUBIC FEET

THE WEIGHTING FACTORS FOR THE EFFECTIVENESS CALCULATION WERE -

ENDURANCE	1.0
TOWING PULL	1.0
DECK AREA AFT	1.0
BOLLARD PULL	1.0
BALLAST	1.0
SHIP DRAFT	1.0
EXCESS VOLUME	1.0
EXCESS STABILITY	1.0

NO PENALTY WAS ASSIGNED FOR EXCESS ENDURANCE OR TOWING PULL

SALVAGE TUG OPTIMIZATION

```
THE PROGRAM HAS EVALUATED A DESIGN BASED ON THE SET OF INITIAL VARIABLE
VALUES PROVIDED AS INPUT PLUS TWENTY-FOUR ADDITIONAL RANDOM DESIGNS AND
FOUND NO ACCEPTABLE INITIAL SOLUTION. THE VALUES OF THE ITEMS CALCULATED
THE LAST SET OF RANDOM VARIABLES ARE LISTED BELOW - ZERO VALUES INDICATE
THAT THE ITEM WAS NOT REACHED FOR CALCULATION.

VALUES OF RANDOM VARIABLES -
   FULL LOAD DISPLACEMENT = 3000.0 TONS, SPEED-LENGTH RATIO = 1.030,
   BEAM-TO-DRAFT RATIO = 3.340, LENGTH-TO-DEPTH RATIO = 11.00, PRISMATIC
   COEFFICIENT = .570

SHIP DIMENSIONS -
   L.B.P.= 278.86 FEET, BEAM = 49.76 FEET, DRAFT = 14.90 FEET,
   DEPTH = 25.35 FEET, FREEBOARD = 10.20 FEET

FORM COEFFICIENTS -
   PRISMATIC =.570, MIDSHIPS =0.951, BLOCK =.508, VOLUMETRIC = .00484

RESISTANCE AND PROPULSION DATA -
   E.H.P.=  200.0, WETTED SURFACE = 31962.1 SQUARE FEET,
   MAXIMUM S.H.P.=  6000.0, ENDURANCE S.H.P.= 1287.1

WEIGHTS -
   GROUP 1   HULL STRUCTURE              1055.27 TONS
   GROUP 2   PROPULSION                   226.42 TONS
   GROUP 3   ELECTRIC PLANT                82.50 TONS
   GROUP 4   COMM AND CONTROL              25.18 TONS
   GROUP 5   AUXILIARY SYSTEMS            555.71 TONS
   GROUP 6   OUTFIT AND FURN.             355.61 TONS
   GROUP 7   ARMAMENT                       2.34 TONS
   LIGHT SHIP DISPLACEMENT               2304.12 TONS

FUEL = 235.2 TONS, RESULTING IN ENDURANCE =      0.0 NAUTICAL MILES.

VOLUME = 262067. CUBIC FEET. THE EXCESS VOLUME = 33105. CUBIC FEET.

STABILITY DATA -
   KG = [illegible] FEET, [illegible] FEET, [illegible] FEET, GM = 4.5[illegible] FEET

EFFECTIVENESS -
   ENDURANCE               0.0           WITH WEIGHT OF  1.0
   TOWING PULL             0.0           WITH WEIGHT OF  1.0
   DECK AREA AFT           0.0           WITH WEIGHT OF  1.0
   BOLLARD PULL            0.0           WITH WEIGHT OF  1.0
   BALLAST                 0.0           WITH WEIGHT OF  1.0
   SHIP DRAFT              0.0           WITH WEIGHT OF  1.0
   EXCESS VOLUME           0.0           WITH WEIGHT OF  1.0
   EXCESS STABILITY        0.0           WITH WEIGHT OF  1.0

COST -
   ACQUISITION COST =  0.0        MILLION DOLLARS
   LIFE CYCLE COST =   0.0        MILLION DOLLARS

COST EFFECTIVENESS =******

RE-EVALUATE LIMITS [illegible] INITIAL VARIABLE VALUES IN LIGHT OF
THE ABOVE RESULTS.
```

THIS TRIAL WAS MADE USING 500 LOOPS IN THE EXPONENTIAL RANDOM SEARCH.
THE NUMBER OF LOOPS AND UPDATING EXPONENT CHANGES WERE AS FOLLOWS -

FIRST 350 LOOPS	EXPONENT = 1
NEXT 100 LOOPS	EXPONENT = 3
NEXT 25 LOOPS	EXPONENT = 5
LAST 25 LOOPS	EXPONENT = 7

THE PARAMETERS CONTROLLING THE SEARCH WERE -

	MINIMUM	MAXIMUM	INITIAL
DISPLACEMENT	2000.000	2600.000	2277.300
SPEED-LENGTH RATIO	0.850	1.090	1.053
BEAM-TO-DRAFT RATIO	2.250	3.750	3.542
LENGTH-TO-DEPTH RATIO	9.000	14.000	12.500
PRISMATIC COEFFICIENT	0.480	0.650	0.542

THE OPERATING CHARACTERISTICS SPECIFIED WERE -

MAXIMUM ALLOWABLE DRAFT = 15.0 FEET
REQUIRED ENDURANCE = 10000.0 NAUTICAL MILES AT 13.0 KNOTS

THE SPEED REQUIREMENTS WERE -

	SPEED	PROP. COEFF.
MAXIMUM	17.2 KNOTS	0.680
ENDURANCE	13.0 KNOTS	0.750
TOWING	7.0 KNOTS	0.650

THE TOW RESISTANCE SPECIFIED WAS 153000.0 POUNDS

NO RESTRICTION WAS PLACED ON MAXIMUM INSTALLED SHP

THE ARMAMENT REQUIREMENTS WERE -

ARMAMENT WEIGHT = 2.34 TONS
AMMUNITION WEIGHT = 11.2 TONS
AMMUNITION VOLUME = 500. CUBIC FEET

THE WEIGHTING FACTORS FOR THE EFFECTIVENESS CALCULATION WERE -

ENDURANCE	1.0
TOWING PULL	1.0
DECK AREA AFT	1.0
BOLLARD PULL	1.0
BALLAST	1.0
SHIP DRAFT	1.0
EXCESS VOLUME	1.0
EXCESS STABILITY	1.0

A PENALTY WAS ASSIGNED FOR EXCESS ENDURANCE AND EXCESS TOWING PULL

SALVAGE TUG OPTIMIZATION
LOOP 479

VALUES OF RANDOM VARIABLES -
FULL LOAD DISPLACEMENT = 2355.4 TONS, SPEED-LENGTH RATIO = 1.026, BEAM-TO-DRAFT RATIO = 3.698, LENGTH-TO-DEPTH RATIO = 13.73, PRISMATIC COEFFICIENT = .499.

SHIP DIMENSIONS -
L.B.P.= 281.23 FEET, BEAM = 47.78 FEET, DRAFT = 12.92 FEET, DEPTH = 20.49 FEET, FREEBOARD = 7.31 FEET

FORM COEFFICIENTS -
PRISMATIC =.499, MIDSHIPS =0.951, BLOCK =.475, VOLUMETRIC = .00371

RESISTANCE AND PROPULSION DATA -
E.H.P.= 664.2, WETTED SURFACE = 12431.7 SQUARE FEET, MAXIMUM S.H.P.= 3488.5, ENDURANCE S.H.P.= 1140.3

WEIGHTS -

GROUP 1	HULL STRUCTURE	825.84 TONS
GROUP 2	PROPULSION	146.72 TONS
GROUP 3	ELECTRIC PLANT	47.30 TONS
GROUP 4	COMM AND CONTROL	15.42 TONS
GROUP 5	AUXILIARY SYSTEMS	504.10 TONS
GROUP 6	OUTFIT AND FURN.	308.43 TONS
GROUP 7	ARMAMENT	2.34 TONS
LIGHT SHIP DISPLACEMENT		1850.15 TONS

FUEL = 134.4 TONS, RESULTING IN ENDURANCE = 9810.2 NAUTICAL MILES.

VOLUME = 191412. CUBIC FEET. THE EXCESS VOLUME = 8652. CUBIC FEET.

STABILITY DATA -
KG = 16.29 FEET, KB = 7.94 FEET, BM = 17.02 FEET, GM = 8.67 FEET

EFFECTIVENESSES -

ENDURANCE	-0.288	WITH WEIGHT OF 1.0
TOWING PULL	-0.000	WITH WEIGHT OF 1.0
DECK AREA AFT	9.497	WITH WEIGHT OF 1.0
BOLLARD PULL	0.983	WITH WEIGHT OF 1.0
BALLAST	0.0	WITH WEIGHT OF 1.0
SHIP DRAFT	1.189	WITH WEIGHT OF 1.0
EXCESS VOLUME	0.462	WITH WEIGHT OF 1.0
EXCESS STABILITY	2.719	WITH WEIGHT OF 1.0

COST -
ACQUISITION COST = 8.851829 MILLION DOLLARS
LIFE CYCLE COST = 20.655350 MILLION DOLLARS

COST EFFECTIVENESS = 0.1803

THE FOLLOWING DESIGN WAS FOUND TO BE THE OPTIMUM OF THE 1475 DESIGNS EVALUATED USING THE EXPONENTIAL RANDOM SEARCH OPTIMIZATION TECHNIQUE.

SHIP DIMENSIONS		FORM COEFFICIENTS		CREW
L.B.P.	281.23 FEET	PRISMATIC	0.499	6 OFFICERS
BEAM	47.78 FEET	MIDSHIPS	0.951	4 C.P.O.
DRAFT	12.92 FEET	BLOCK	0.475	59 ENLISTED
DEPTH	20.49 FEET	VOLUMETRIC	0.00371	
S.S.B.*	25.49 FEET	WATERPLANE	0.723	

E.H.P.= 664.2, MAXIMUM S.H.P.= 3488.5, ENDURANCE S.H.P.= 1140.3
WETTED SURFACE = 12431.7 SQUARE FEET

GROUP 1 HULL STRUCTURE	825.8 TONS
GROUP 2 PROPULSION	146.7 TONS
GROUP 3 ELECTRIC PLANT	47.3 TONS
GROUP 4 COMM AND CONTROL	15.4 TONS
GROUP 5 AUXILIARY SYSTEMS	504.1 TONS
GROUP 6 OUTFIT AND FURN.	308.4 TONS
GROUP 7 ARMAMENT	2.3 TONS
LIGHT SHIP DISPL (W/O MARGINS)	1850.2 TONS
BUILDERS MARGIN	18.5 TONS
DESIGN MARGIN	74.0 TONS
CHANGE ORDERS	22.2 TONS
GOVT FURNISHED MATERIAL	14.8 TONS
LIGHT SHIP DISPL (WITH MARGINS)	1979.7 TONS
SHIP OFFICERS, CREW AND EFFECTS	7.7 TONS
SHIP AMMUNITION	11.2 TONS
PROVISIONS AND PERSONNEL STORES	12.7 TONS
GENERAL STORES	11.7 TONS
POTABLE WATER	63.9 TONS
LUBRICATING OIL, SHIP	8.7 TONS
DIESEL OIL	134.4 TONS
FOAM LIQUID	8.2 TONS
GASES	14.8 TONS
SALVAGE EQUIPMENT	102.3 TONS
FULL LOAD DISPLACEMENT (WITH MARGINS)	2355.4 TONS

* THIS IS THE BREADTH OF THE LOWER SUPERSTRUCTURE DECK. THE UPPER DECK OF THE SUPERSTRUCTURE IS SIX FEET LESS IN BREADTH. THE SUPERSTRUCTURE IS ONE-QUARTER OF THE L.B.P. IN LENGTH.

VOLUMES

TOTAL VOLUME AVAILABLE	191412. CUBIC FEET
PROVISIONS AND STORES VOLUME	3519. CUBIC FEET
SALVAGE STORES VOLUME	34450. CUBIC FEET
BERTHING SPACE VOLUME	12468. CUBIC FEET
MESSING SPACE VOLUME	5239. CUBIC FEET
SANITARY SPACE VOLUME	3294. CUBIC FEET
BAGGAGE STOWAGE VOLUME	344. CUBIC FEET
OFFICE SPACE VOLUME	10480. CUBIC FEET
PASSAGEWAY VOLUME	11731. CUBIC FEET
FAN ROOM AND UPTAKE SPACE VOLUME	5752. CUBIC FEET
DECK GEAR AND MISC. LOCKERS VOL.	1280. CUBIC FEET
SHOP VOLUMES	20400. CUBIC FEET
WINDLASS ROOM AND CHAIN LKR VOL.	6230. CUBIC FEET
STEERING GEAR ROOM VOLUME	6400. CUBIC FEET
AMMUNITION VOLUME	500. CUBIC FEET
MACHINERY SPACE VOLUME *	45453. CUBIC FEET
FUEL OIL TANK VOLUME	6086. CUBIC FEET
FRESH WATER TANK VOLUME	2300. CUBIC FEET
LUBE OIL TANK VOLUME	358. CUBIC FEET
BALLAST TANK VOLUME	6476. CUBIC FEET
EXCESS VOLUME	8652. CUBIC FEET

STABILITY

KB = 7.94 FEET
BM = 17.02 FEET
KG = 16.29 FEET
GM = 8.67 FEET

EXCESS GM ** = 3.89 FEET

MISCELLANEOUS

TOWING PULL	153000. POUNDS
BOLLARD PULL	87211. POUNDS
DECK AREA AFT	4479. SQUARE FEET

COST

ACQUISITION COST	8.851829 MILLION DOLLARS
ANNUAL CREW COSTS	0.484000 MILLION DOLLARS
ANNUAL UPKEEP COST	0.271567 MILLION DOLLARS
LIFE CYCLE COST	20.655350 MILLION DOLLARS

* THE MACHINERY SPACE VOLUME WAS COMPUTED FROM A CALCULATED REQUIRED ENGINEERING SPACE LENGTH OF 57.70 FEET.

** THE EXCESS GM IS COMPUTED BY ASSUMING A REQUIRED GM (UNCORRECTED FOR FREE SURFACE) OF TEN PERCENT OF THE SHIPS BEAM